TECHNICAL REPORT
NATICK/TR-82/022

20000731238

A Mathematical Model
of the
Inertial Properties of
a Carrier-Backpack System
Volume IV

BY PHILIP E. MARTIN
RICHARD N. HINRICHS
IN-SIK SHIN
AND
RICHARD C. NELSON

BIOMECHANICS LABORATORY
THE PENNSYLVANIA STATE UNIVERSITY
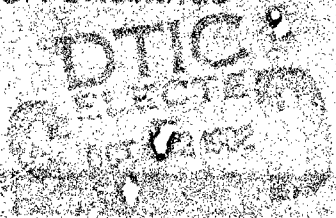UNIVERSITY PARK, PENNSYLVANIA

MAY 1982

UNITED STATES ARMY NATICK
RESEARCH & DEVELOPMENT LABORATORIES
NATICK, MASSACHUSETTS 01760

APPROVED FOR PUBLIC RELEASE; DISTRIBUTION UNLIMITED

DTIC

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER NATICK/TR-82/022	2. GOVT ACCESSION NO. AD-A120163	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) VOLUME IV. A MATHEMATICAL MODEL OF THE INERTIAL PROPERTIES OF A CARRIER-BACKPACK SYSTEM		5. TYPE OF REPORT & PERIOD COVERED Final Report for Period October 1, 1979 to August 31,1981
		6. PERFORMING ORG. REPORT NUMBER IPL-252
7. AUTHOR(s) Philip E. Martin, M.S., Richard N. Hinrichs, M.S., In-Sik Shin, B.S., and Richard C. Nelson, Ph.D.		8. CONTRACT OR GRANT NUMBER(s) DAAK60-79-C-0131
9. PERFORMING ORGANIZATION NAME AND ADDRESS Biomechanics Laboratory The Pennsylvania State University University Park, Pennsylvania 16802		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 6.2, 1L162723AH98AJ005
11. CONTROLLING OFFICE NAME AND ADDRESS US Army Natick Research and Development Laboratories ATTN: DRDNA-ICCH Natick, Massachusetts 01760		12. REPORT DATE May 1982
		13. NUMBER OF PAGES 83
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Backpacks	Loads
Backpack System	Human Backpack System
Mathematic Models	Load Carrying
Carrier Backpack System	Inertial Properties
Computer Models	

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a report on the development of a mathematical model and Fortran program to examine the inertial properties of a human-backpack system. A twelve-segment model was formulated to represent a soldier carrying a backpack and other objects often carried during military operations. This computer model is used to generate values of the following variables: system mass, system center of mass location, system inertia tensor, and principal moments of inertia for the system. The model can be used to simulate both a male and a female human body. Any one of four backpack systems, each containing a 20-lb load, can be

DD FORM 1473 EDITION OF 1 NOV 65 IS OBSOLETE

examined. Three of the backpacks have external frames and one has an internal
frame. One or two loads, the weights of which are determined by the program
user can be added to the 20-lb pack load. The positioning of these added loads
is also user-determined. In this report, the development of the model is
discussed and results of executions of the program are presented. In addition,
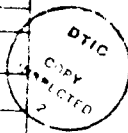the report contains a listing of the Fortran program.

PREFACE

This is the fourth of four volumes comprising the final report of research performed under Contract Number DAAK60-79-C-0131 with the Individual Protection Laboratory, US Army Natick Research and Development Laboratories, Natick, Massachusetts. The work was formulated and directed by Drs. Carolyn K. Bensel and Richard F. Johnson, Human Factors Group, Individual Protection Laboratory. Dr. Bensel was the contract monitor and Dr. Johnson was the alternate.

Table of Contents

List of Figures

List of Tables

5

A Mathematical Model of the Inertial
Properties of a Carrier-Backpack System

INTRODUCTION

In the field of biomechanics, researchers use a variety of research
techniques to evaluate various aspects of physical performance. Mathematical
modeling is one analysis technique which is available to the biomechanics
researcher for relating performance to the mechanical characteristics of
the system under investigation.

According to Olinick,[1] a researcher may develop conclusions about a
situation under observation by conducting controlled experiments and recording
the results or by developing a model which, when carefully designed, will
eventually lead to the same conclusions as experimentation. The advantage
of mathematical modeling is that a model is free of the physical limitations
often associated with experimental research. Selected variables of interest
can be isolated and carefully controlled.

There are basically two classifications of mathematical models which are
commonly used: deterministic and probabilistic. Deterministic models are
those which are based on exact relationships such that, for any given input,
the exact end result may be determined. Probabilistic models, as the name
implies, are based on the assumption that an observation or system under
investigation can occupy one of several different states with different
probabilities at any given moment. Consequently, inferential statistics play
an important role in the development and evaluation of these models. In either
case, the goal of the researcher is to develop the most accurate, yet simple,
model possible.

In this project a deterministic model was developed to examine the
inertial characteristics of a human-backpack system. In any system, the accelera-
tion of a body is related to the inertial properties of the body. In the case
of linear motion, the mass of an object represents the resistance to linear
acceleration. When considering angular motion, however, one must be concerned
not only with the magnitude of the object's mass, but also with how that mass is
distributed about some axis of rotation. The moment of inertia of an object
takes into consideration both mass and the distribution of that mass and thus
represents the resistance of that object to angular acceleration.

The inertial properties of a human-pack system are quite important to
the ability of an individual to make rapid movements, either linear or angular
in nature. For example, a soldier in a combat situation may be required to
make some evasive maneuver. A greater mass and greater moment of inertia of
the soldier-pack system would inhibit the ability of the soldier to make
rapid linear and angular accelerations, respectively.

---

[1] Olinick, M., An Introduction to Mathematical Models in the Social and Life
Sciences. Reading, Massachusetts: Addison Wesley Publishing Company, 1978.

Because a pack can be loaded in various ways, an individual has some control over the inertial properties of a pack and the influence of the pack inertial properties on the entire carrier-pack system. Consequently, it was the purpose of this project to examine the inertial characteristics of the total carrier-backpack system using a mathematical model. The system was designed so that both male and female models could be examined in conjunction with four different backpacks.

The work performed in this project was an extension of that done previously by Hinrichs, Lallemant, and Nelson.[2] In their work they examined the inertial properties of three backpacks of different design while manipulating the loading configurations of the packs. In discussing the results, they summarized certain inertial properties which are desirable in a backpack, based on mechanical principles. These included having the smallest possible mass, having the dorso-ventral center of gravity (CG) component as close to the body as possible, having the pack symmetrically loaded from side to side, having the longitudinal CG component as low as possible, and having the smallest possible moments of inertia. The authors were quick to point out that these desirable characteristics are not always feasible. With this limitation in mind, their results suggested that the most desirable combinations of the loading configurations examined would be to load the equipment low and place any added weight on the sides and/or the bottom of the pack. In addition, any extra weight should be placed as close to the pack frame as possible.

PROCEDURES

In this phase of the work on load carrying behavior, a computer model was developed to estimate the inertial properties of a human-backpack system. In order to understand the methods used in this phase, the reader should have some basic understanding of rigid body dynamics. Because this information can be obtained from any number of texts (eg., Synge and Griffith, 1942; Greenwood, 1970; or Beer and Johnston, 1977), it will not be discussed in this write-up. The reader is also referred to Hinrichs et al. for discussion of basic mechanical considerations.[2] Their discussion is quite appropriate for this project.

Twelve Segment Model

For the purpose of this phase of the project, a twelve segment model was developed to represent a soldier wearing a pack and other common objects normally carried in combat. Information on the items included is presented in Appendix A. Because the principal objective of this phase was to estimate

---

[2] Hinrichs, R.N., S.R. Lallemant, and R.C. Nelson. An Investigation of the Inertial Properties of Backpacks Loaded in Various Configurations. (Tech. Rep. NATICK/TR-82/023). Natick, Massachusetts: U.S. Army Natick Research and Development Laboratories, May 1982.

the influence of the backpack type and load on the inertial characteristics of the entire system, the values of inertial variables for all segments, excep. the backpack and added load, were fixed. The computer model was developed so that one of four backpacks, ALICE LC-2, ALICE LC-1, LOCO, and PACKBOARD, could be used in conjunction with one, two, or no added loads. The backpack systems are described in Appendix A. In addition, the program allowed for the incorporation of either a male or female human body.

In developing the model, a common coordinate system was used so that each segment could be appropriately positioned relative to all other segments. The origin of the coordinate system was fixed at a point between the feet of the body at ground level. The X-axis represented a dorso-ventral axis, the Y-axis a transverse axis, and the Z-axis a longitudinal axis. Figure 1 gives a general representation of these three axes relative to a human body model.

A description of each of the twelve segments incorporated into the model follows.

Human Body (Segment 1). The human body was treated as a rigid body in this project. Several sources of information were used to construct both male and female models. The stature, mass, and necessary body coordinates were obtained or derived using the anthropometric data from two separate reports: The Body Size of Soldiers: U.S. Army Anthropometry - 1966[3] and Anthropometry of Women of the U.S. Army - 1977.[4] For both the male and the female models, 50th percentile data were used. These values were also adjusted for the inclusion of the Army-issue utility shirt and trousers. These anthropometric data were then used in conjunction with the inertial data reported by Hanavan[5] who developed a mathematical model of the human body in an attempt to estimate the inertial properties of the body in many different fixed positions. For this model, Hanavan's position 21, which is that shown in Figure 1, was selected. This body position seemed to most closely approximate the position of a soldier carrying a rifle in front of his body. Again using 50th percentile data, the location of the body center of gravity and the body moments of inertia were derived from Hanavan's data. Because the available inertia values were for an individual with a body mass of 74.2 kg and a stature of 1.755 m, they had to be

---

[3]White, R.M. and E. Churchill. The Body Size of Soldiers: U.S. Army Anthropometry - 1966 (Tech. Rep. 72-81-CE). Natick, Massachusetts: United States Army Natick Laboratories, December 1971.

[4]Churchill, E., T. Churchill, J.T. McConville, and M. White. Anthropometry of Women of the U.S. Army - 1977 (Tech. Rep. NATICK/TR-77/024). Natick, Massachusetts: United States Army Natick Research and Development Command, June 1977.

[5]Hanavan, E.P. A Mathematical Model of the Human Body (Tech. Rep. AMRL-TR-64-102). Wrigth-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratories, 1964.
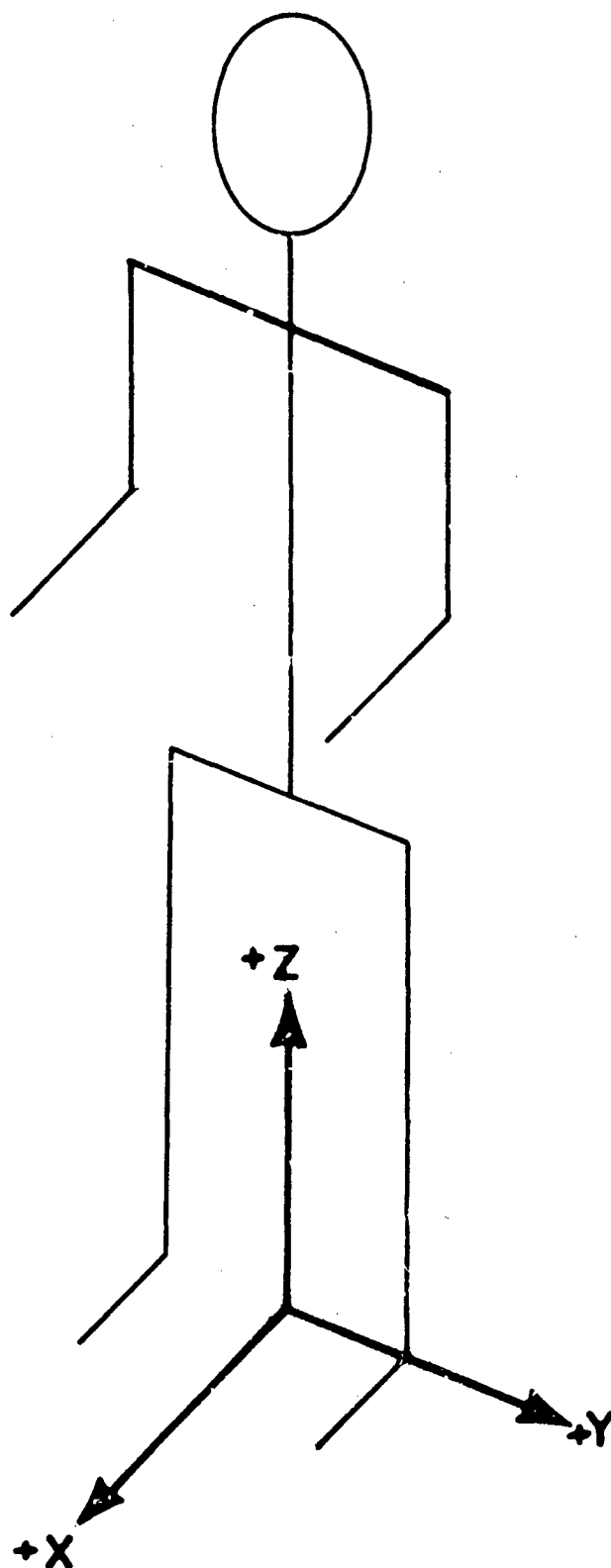
Figure 1. Representation of the fixed coordinate axes for the entire carrier-pack system.

adjusted for the male and the female models used in this study. These adjustments were made by using correction factors based on stature and body mass. These can be shown mathematically as follows:

$$I_{LA} = \left(\frac{M_A^2 \cdot S_H}{M_H^2 \cdot S_A} \right) I_{LH} \qquad I_{TA} = \left(\frac{M_A \cdot S_A^2}{M_H \cdot S_H^2} \right) I_{TH} \qquad I_{DA} = \left(\frac{M_A \cdot S_A^2}{M_H \cdot S_H^2} \right) I_{DH}$$

where I_{LA}, I_{TA}, and I_{DA} are the adjusted moment of inertia values for the longitudinal, transverse, and dorso-ventral axes, respectively; I_{LH}, I_{TH}, and I_{DH} are the inertia values from Hanavan; M_A and S_A are the male or female model mass and stature values; and M_H and S_H are the mass and stature values from Hanavan. This adjustment is a minor one for the male model but is relatively large for the female model. Because of the lack of inertia data for females, this adjustment for the female model represents a limitation. It was felt, however, that it would have a relatively minor effect on the results. The rationale for this adjustment method was provided by Hinrichs.[6]

Helmet (Segment 2). Many of the twelve segments were modeled as point masses rather than rigid bodies. This greatly simplifies the necessary input data since a point mass has no moments or products of inertia. This is an appropriate assumption as long as the transfer term from a local coordinate system to a coordinate system located at the total system center of mass dominates the segment's moments of inertia. This simplifying assumption will not lead to any significant error when applied to those segments of relatively small size and mass. The helmet was one such segment and consequently was represented as a point mass. The center of mass location for the helmet was determined using the reaction-board technique. This center of mass location was then used to locate the helmet relative to the top of the head.

Fighting Gear Elements (Segments 3-6). Each of the four fighting gear elements was represented as a point mass. Rather than determining center of mass positions for the four elements, each was considered as a regular rectangular shape with the center of mass coincident with the geometric center. The four elements were then positioned around the trunk of the body using selected anthropometric measures presented in the 1966 and 1977 anthropometric reports. (Ref. 3 and 4). Figure 2 shows the positioning of the four elements in the transverse and dorso-ventral directions. The location of the elements in these two directions was based on measures of hip breadth (transverse) and waist depth (dorso-ventral). All four elements were positioned along the longitudinal axis at the level of the trochanters of the femurs.

---

[6]Hinrichs, R.N. "Principal Axes and Moments of Inertia of the Human Body: An Investigation of the Stability of Rotary Motions." Unpublished Masters Thesis, University of Iowa, Iowa City, Iowa, 1978.
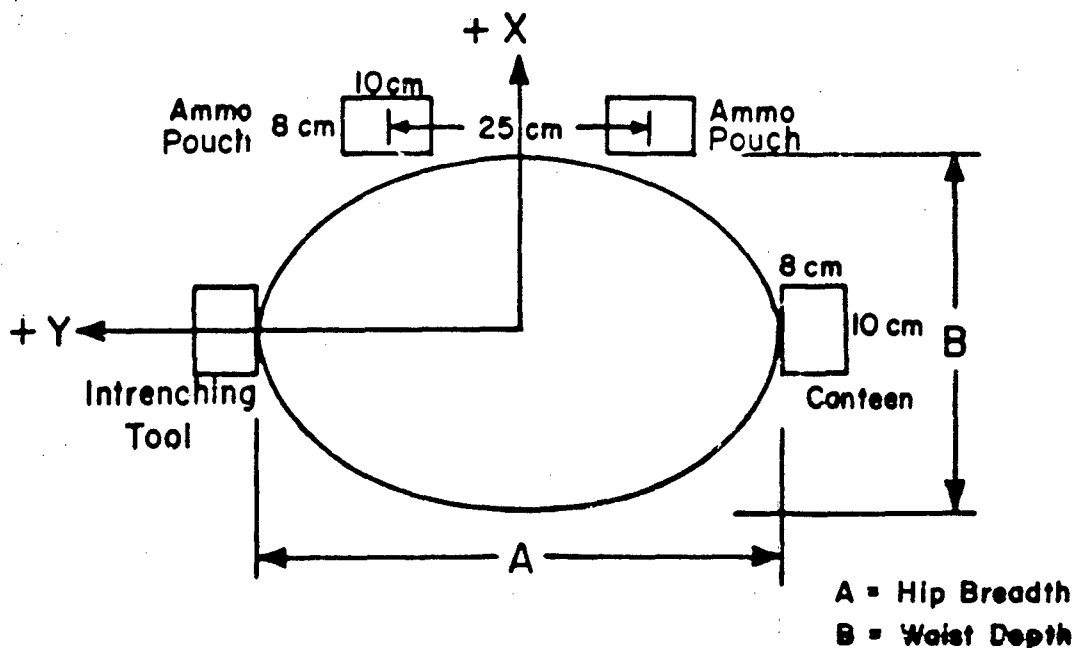
Figure 2. Position of the four fighting gear elements along
the transverse (Y) and dorso-ventral (X) axes.

Boots (Segments 7-8). Both boots were modeled as point masses as well.
Because the center of mass of the boot was quite close to the approximated
center of mass of the foot segment, the coordinates of the foot center of
mass were used to represent the location of the boot.

Rifle (Segment 9). Since the rifle is much larger and has a greater
mass than those segments treated as point masses, it was more appropriately
modeled as a rigid body. By using the reaction-board technique, the
location of the center of mass was determined. Then, by using an oscillation
technique which was previously used by Hinrichs et al. (Ref. 2), the moments
and products of inertia were derived. In order to define unit vectors along
the three local axes of the rifle, three points were established on the
rifle. Figure 3 shows the location of these points (A,B,C) and the local
coordinate axes. Point A was also used to position the rifle relative to
the body since it was assumed that the right hand gripped the rifle at
this point. In this model the rifle was positioned horizontally in front
of the body. Consequently, knowledge of the location of the right hand on
the rifle determines the position of the left hand on the rifle. By knowing
the coordinates of the right hand in the fixed coordinate system, the
location of the center of mass of the rifle was easily transformed from
local to system coordinates.
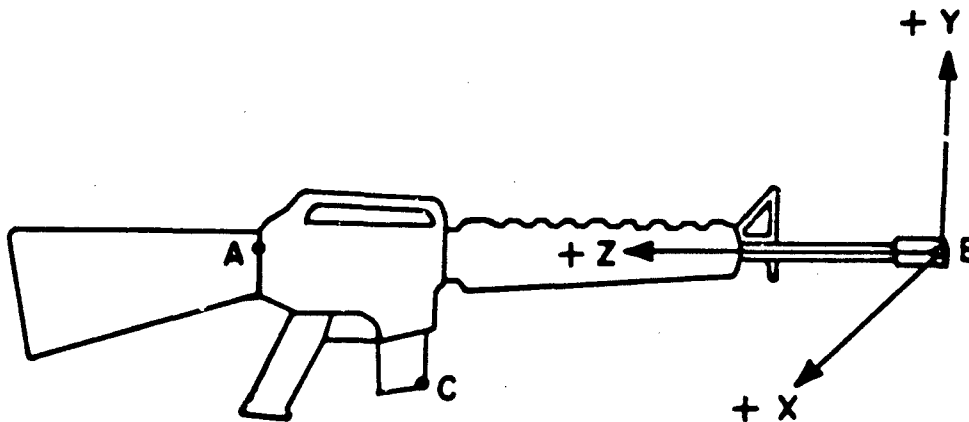
Figure 3. Representation of the rifle local coordinate system and three points on the rifle used to define unit vectors along the three axes.

The nine segments defined thus far are those which were assumed to be fixed in the computer model. Their inertial properties are summarized in Table 1.

Backpacks (Segment 10). The origin of the local coordinate axes for each backpack was located at the center of mass of the backpack with the axes oriented parallel to the fixed coordinate axes. The local z-axis of the backpack was aligned parallel to the line connecting the contact points of the pack on the body at the shoulders and hip. This assured the backpacks would have the proper orientation relative to the body. The same reaction-board and oscillation techniques were used to estimate center of mass location and the inertial properties for each backpack. For these tests, each pack was loaded with a sleeping bag, mattress, waterproof clothes bag, poncho, socks and undershirt. These items, excluding the backpack, totalled 9.07 kg. Estimates were then made of the location of each pack relative to the shoulder joints. In the dorso-ventral direction, the edge of each pack closest to the body was positioned 10 centimeters from the X coordinate of the shoulder. For the transverse direction, each pack was assumed to be centered on the logitudinal axis of the body. Along the longitudinal axis, the tops of the ALICE LC-2, ALICE LC-1, and PACKBOARD were positioned at the same level as the shoulders. Only the top of the LOCO was positioned differently. It was positioned 10 centimeters above the level of the shoulders because of its greater length. By representing the local centers of mass as proportions of the dimensions of the packs and then relative to the shoulders, the center of mass locations were transformed to the system coordinate axes. Table 2 summarizes the inertial properties of the four packs.

13

Table 1

Inertial Properties for the Nine Fixed Segments of the
Human-Backpack System

Segment*	Segment Mass (kg)	Center of Mass Coordinates (m)**			Moments of Inertia (kg·m²)			Products of Inertia (kg·m²)		
		X	Y	Z	XX	YY	ZZ	XY	XZ	YZ
Male human body (R)	72.66	0.094	0.0	0.959	11.84	11.39	1.03	0.0	0.0	0.0
Female human body (R)	61.21	0.088	0.0	0.901	8.69	8.36	0.79	0.0	0.0	0.0
Helmet (P)	1.47	0.0	0.0	1.679	0.0	0.0	0.0	0.0	0.0	0.0
Intrenching Tool (P)	1.20	0.0	0.205	0.917	0.0	0.0	0.0	0.0	0.0	0.0
Ammo Pouch 1 (P)	1.76	0.175	0.125	0.917	0.0	0.0	0.0	0.0	0.0	0.0
Ammo Pouch 2 (P)	1.76	0.175	-0.125	0.917	0.0	0.0	0.0	0.0	0.0	0.0
Canteen (P)	1.26	0.0	-0.205	0.917	0.0	0.0	0.0	0.0	0.0	0.0
Left Boot (P)	0.85	0.120	0.165	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Right Boot (P)	0.85	0.120	-0.165	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Rifle, M-16 (R)	3.37	0.384	0.074	1.067	0.22	0.21	0.01	0.002	0.004	-0.003

* Each segment was modeled as either a rigid body or a point mass. This is indicated in parentheses next
  to the segment name by using either an R for rigid body or a P for point mass.

** The coordinate values reported are those used in conjunction with the male model. There were small
   differences in the coordinate values when comparing the male with the female application. These
   differences are the result of differences in body size.

14

Table 2

Inertial Properties of the Four Backpacks

Pack	Mass (kg)	Pack Dimensions (m)			Center of Mass (m)*			Moments of Inertia $(kg \cdot m^2)$			Products of Inertia $(kg \cdot m^2)$		
		X	Y	Z	X	Y	Z	XX	YY	ZZ	YY	XZ	YZ
ALICE LC-2	12.51	0.40	0.46	0.51	0.49	0.50	0.51	0.35	0.35	0.45	-0.001	-0.095	-0.024
ALICE LC-1	12.09	0.39	0.46	0.51	0.50	0.50	0.52	0.35	0.34	0.48	0.008	-0.081	-0.005
LOCO	10.63	0.28	0.37	0.63	0.38	0.50	0.67	0.40	0.30	0.39	0.009	0.241	0.137
PACKBOARD	12.87	0.29	0.46	0.55	0.47	0.48	0.49	0.48	0.41	0.54	-0.004	0.056	0.079

* Center of mass values are represented as a proportion of the pack dimensions. The X value was measured from the edge of the pack closest to the body, the Y value from the left edge of the pack, and the Z value from the top of the pack.

Added Loads (Segments 11-12). The computer model allows for the possible addition of one or two loads of variable mass to the pack in the form of point masses. The loads can be placed in any position within the pack by specifying the locations as proportions of the pack's three dimensions. In this way, a variety of loading conditions could be simulated.

Loading Configurations

To examine the influence of different loading conditions on the inertial prope.ties of the human-backpack system, seven loading configurations were simulated for both a male and a female model and for each of four backpacks. With one exception, the loading configurations were simulated under conditions of one and of two added loads. Each added load was 6.80 kg. Thus, the pack loads simulated totalled 9.07, 15.87, and 22.67 kg. These values were chosen because they are identical to pack load weights used in other studies conducted under this contract.[7,8,9] These studies entailed analyses of the effects of load carrying on the performance capabilities of men and women. For configurations 2 through 7, the positioning of the added loads were represented as a proportion of the pack dimensions. For the dorso-ventral direction (X), 0% represented the edge of the pack closer to the body. For the transverse direction (Y), 0% would be on the side of the pack representing the models left side. Finally, for the longitudinal direction (Z), 0% represented the top of the pack. The following is a brief summary of the seven loading configurations. Values in parentheses represent the proportions used in locating the added loads in the X, Y and Z directions, respectively.

1.   No added load. Both of the added loads were set to zero so that only the basic, 9.07-kg load was included within the pack.

2. a,b.   Performance testing position (PTP). The added loads were positioned such that they estimated the positioning of loads added to the packs during the performance testing studies (Refs. 7,8,9). This position was near the top of the pack and close to the body. (.10, .50, .20).

3. a,b.   High loading. The added loads were positioned near the top of the pack and were centered in the pack with respect to its dorso-ventral (X) and transverse (Y) axes. (.50, .50, .10).

---

[7]Nelson, R.C. and P.E. Martin. Volume I. Effects of Gender and Load on Combative Movement Performance (Tech. Rep. NATICK/TR-82/011). Natick, Massachusetts: US Army Natick Research and Development Laboratories, February 1982.

[8]Nelson, R.C. and P.E. Martin. Volume II. Effects of Gender, Load, and Backpack on Easy Standing and Vertical Jump Performance (Tech. Rep. NATICK/TR-82/016). Natick, Massachusetts: US Army Natick Research and Development Laboratories, March 1982.

[9]Martin, P.E. and R.C. Nelson. Volume III. Effects of Gender, Load, and Backpack on the Temporal and Kinematic Characteristics of Walking Gait (Tech. Rep. NATICK/TR-82/021). Natick, Massachusetts: US Army Natick Research and Development Laboratories, April 1982.

4. a,b. Low loading. The positioning of the added loads was the same as that for the high loading, except along the longitudinal (Z) axis, where the loads were placed near the bottom of the pack. (.50, .50, .90).

5. a,b. Front loading. The added loads were centered with respect to the longitudinal (Z) and transverse (Y) axes of the pack, but were positioned close to the body. (.10, .50, .50)

6. a,b. Back loading. The added loads were again centered with respect to the longitudinal (Z) and transverse (Y) axes, but were positioned near the edge of the pack farthest from the body. (.90, .50, .50).

7. a,b. Side-to-Side loading (S-to-S). The added loads were positioned near the left and the right edges of the pack and were centered along the longitudinal (Z) and dorso-ventral (X) axes of the body. (.50, .10, .50 for half of the load and .50, .90, .50 for the other half).

Calculated Variables

The computer model developed for this phase of the project was adapted from a similar program written by Richard N. Hinrichs (Ref. 6) for his investigation of the stability of rotary motion. The computer model generated values for the following variables which described the inertial characteristics of the entire human-pack system: 1. System mass – the total mass of all components of the model. 2. System center of mass location – the X, Y, and Z values of the center of mass of the system with respect to the fixed coordinate system. 3. System inertia tensor represented at the system center of mass, which includes the moments and products of inertia for a system of axes parallel to the three fixed axes and whose origin lies at the center of mass. These describe how the total mass is distributed about the three axes. 4. Principal moments of inertia and their direction cosines from the three fixed axes. These represent moments of inertia of the total mass about a new set of axes oriented such that the products of inertia are eliminated. The system inertia tensor and principal moments of inertia with direction cosines provide the same information to the program user but in different formats. For this reason, only the values of the inertia tensor will be reported and discussed in this document. The reader is again referred to such sources as Greenwood (1970) or Beer and Johnston (1977) for details of inertia tensors and principal moments of inertia and their interpretation.

In addition, the model was developed so that it would have a certain degree of flexibility. The program user has the option of selecting either a male or a female model and any one of the four backpacks used in the testing, and of using no, one, or two added loads of variable magnitude positioned anywhere within the pack. Separate data decks were developed for the male and the female models so the user need only incorporate the appropriate deck in the computer analysis. The other options can be selected simply by adjusting input values of selected variables on a few cards of the data deck. For example, the subroutine LDDAT of the computer program reads in values

17

of the extra loads desired and calculates their location based on information
specified by the user. If the user prefers to use no added load, the
magnitudes for the added loads in the data deck must be set to zero. To
establish the location of any non-zero load, the user must manipulate the
proportions of the three pack dimensions to be read in from the data deck.
These adjustments are all quite simple to make as long as the user takes
care in selecting the appropriate cards from the data deck to be changed.

Although a certain amount of flexibility has been created in the
development of the computer model, there are limitations to the use of the
model. This is particularly true when considering the characteristics of
the carrier used in the model. The human body (Segment 1 of the model) was
developed as being a 50th percentile male or female in stature and body mass.
Because the emphasis of the model was to examine the effects of gender, back-
pack, and load on the inertial properties of the total system, no attempt
was made to incorporate other percentile levels for the human body, although
this could be done if desired. In addition, some limits are not established
by the program itself but should be by the user. For example, there is no
specific limit on the possible magnitude of added loads except that imposed
by the format used in reading this data in the program. It makes little
sense however, to incorporate loads beyond those typically used in the
military.

RESULTS AND DISCUSSION

In two other studies conducted under this contract, the effects of three main factors - gender, backpack, and load - on selected characteristics of standing, vertical jumping, and walking were examined (Refs. 8,9). Because of the design of the computer model developed for this study, the effects of these same three factors on the interial properties of the carrier-backpack system can be examined. In addition, a fourth factor, loading position, is included. The influence of these four factors will be discussed in terms of three basic variables: mass, center of mass location, and moments of inertia.

Tables 3 through 10 present results obtained from executions of the computer model. Because the trends are quite similar across the four factors, specific results will not be discussed for each condition examined. Rather, general trends found in the data will be presented.

Gender

Comparing the results for the male model presented in Tables 3 to 6 with those for the female model shown in Tables 7 to 10 demonstrated that the male values for system mass and the three moments of inertia were greater than the female values for the same variables under all conditions tested. These results provide no new information since it is common knowledge that an average male has a greater body mass than an average female. This difference in body mass is responsible not only for the difference in system mass but also for the difference in the values for moment of inertia.

These greater values for the male model indicated a greater resistance to both linear and angular accelerations existed for the male than for the female. This does not indicate, however, that it is easier for the female to accelerate in these directions. Since the ability to produce a linear acceleration is directly proportional to the force acting to cause the acceleration, one must consider the force-producing capabilities for the male and female. An important and well-known difference between the sexes is the ratio of strength to body mass, which is normally greater for the male. This means that, even though the male has a greater mass to accelerate, he generally has a greater capacity to generate force. Consequently, any advantage the female may have in the form of smaller body mass may well be lost due to a lesser capacity for generating force. The same situation exists for angular accelerations since the ability to produce an angular acceleration is directly related to the torque generated by an individual. Although the female has an advantage in terms of a smaller moment of inertia, this advantage is lost due to a decreased ability to generate torque.

Finally, a comparison of the locations of the centers of mass for the male and the female showed that the greatest difference existed for the Z component. This was expected since the coordinate system was fixed near the feet and an average female is many centimeters shorter than an average male. Very little difference existed for the X and Y components, although the X

Table 3

Inertial Properties for Male with ALICE LC-2

Loading Condition	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m^2)					
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1. No added load	97.68	0.054	0.002	0.982	15.55	16.76	4.00	-0.08	0.91	-0.05
2a. 6.80 kg – PTP	104.48	0.041	0.002	1.005	16.33	17.78	4.24	-0.08	1.35	-0.04
2b. 13.60 kg – PTP	111.28	0.030	0.002	1.025	17.03	18.68	4.45	-0.09	1.73	-0.04
3a. 6.80 kg – High	104.48	0.031	0.002	1.008	16.58	18.58	4.80	-0.09	1.82	-0.04
3b. 13.60 kg – High	111.28	0.010	0.002	1.031	17.49	20.19	5.49	-0.09	2.61	-0.04
4a. 6.80 kg – Low	104.48	0.031	0.002	0.982	15.55	17.55	4.80	-0.09	0.90	-0.05
4t. 13.60 kg – Low	111.28	0.010	0.002	0.981	15.55	18.25	5.49	-0.09	0.89	-0.05
5a. 6.80 kg – Front	104.48	0.041	0.002	0.995	15.80	17.25	4.24	-0.08	1.1	-0.05
5b. 13.60 kg – Front	111.28	0.030	0.002	1.006	16.02	17.68	4.45	-0.09	1.37	-0.04
6a. 6.80 kg – Back	104.48	0.020	0.002	0.995	15.80	18.69	5.68	-0.09	1.50	-0.05
6b. 13.60 kg – Back	111.28	-0.009	0.002	1.006	16.02	20.38	7.15	-0.10	2.13	-0.04
7a. 6.80 kg – S-to-S	104.48	0.031	0.002	0.995	16.03	17.80	5.03	-0.09	1.36	-0.05
7b. 13.60 kg – S-to-S	111.28	0.010	0.002	1.006	16.48	18.72	5.95	-0.09	1.75	-0.04

Table 4

Inertial Properties for Male with ALICE LC-1.

	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m^2)					
Loading Condition		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1. No added load	97.26	0.055	0.002	0.981	15.50	16.65	3.97	-0.07	0.87	-0.03
2a. 6.80 kg – PTP	104.06	0.043	0.002	1.004	16.30	17.68	4.21	-0.07	1.31	-0.02
2b. 13.60 kg – PTP	110.86	0.031	0.002	1.024	16.99	18.59	4.42	-0.08	1.69	-0.02
3a. 6.80 kg – High	104.06	0.032	0.002	1.007	16.54	18.47	4.75	-0.08	1.77	-0.02
3b. 13.60 kg – High	110.86	0.012	0.002	1.030	17.45	20.06	5.44	-0.08	2.56	-0.02
4a. 6.80 kg – Low	104.06	0.032	0.002	0.980	15.50	17.43	4.75	-0.08	0.87	-0.03
4b. 13.60 kg – Low	110.86	0.012	0.002	0.980	15.50	18.11	5.44	-0.08	0.86	-0.03
5a. 6.80 kg – Front	104.06	0.043	0.002	0.994	15.76	17.14	4.21	-0.07	1.12	-0.03
5b. 13.60 kg – Front	110.86	0.031	0.002	1.005	15.98	17.58	4.42	-0.08	1.34	-0.02
6a. 6.80 kg – Back	104.06	0.022	0.002	0.994	15.76	18.53	5.60	-0.08	1.52	-0.03
6b. 13.60 kg – Back	110.86	-0.007	0.002	1.005	15.98	20.18	7.03	-0.09	2.09	-0.02
7a. 6.80 kg – S-to-S	104.08	0.032	0.002	0.994	15.99	17.68	4.98	-0.08	1.32	-0.03
7b. 13.60 kg – S-to-S	110.85	0.012	0.002	1.005	16.44	18.59	5.90	-0.08	1.71	-0.02

Table 5

Inertial Properties for Male with LOCO

Loading Condition	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m²)					
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1. No added load	95.80	0.070	0.002	0.971	15.30	15.56	3.10	-0.07	0.75	0.11
2a. 6.80 kg - PTP	102.60	0.057	0.002	1.000	16.52	17.04	3.35	-0.07	1.30	0.12
2b. 13.60 kg - PTP	109.40	0.046	0.002	1.026	17.59	18.33	3.57	-0.07	1.78	0.12
3a. 6.80 kg - High	102.60	0.050	0.002	1.005	16.90	17.77	3.71	-0.07	1.74	0.12
3b. 13.60 kg - High	109.40	0.032	0.002	1.034	18.29	19.71	4.25	-0.08	2.60	0.12
4a. 6.80 kg - Low	102.60	0.050	0.002	0.971	15.30	16.18	3.71	-0.07	0.74	0.11
4b. 13.60 kg - Low	109.40	0.032	0.002	0.971	15.30	16.71	4.25	-0.08	0.74	0.11
5a. 6.80 kg - Front	102.60	0.057	0.002	0.988	15.69	16.21	3.35	-0.07	1.06	0.11
5b. 13.60 kg - Front	109.40	0.046	0.002	1.002	16.04	16.78	3.57	-0.07	1.34	0.12
6a. 6.80 kg - Back	102.60	0.042	0.002	0.988	15.69	17.09	4.23	-0.07	1.42	0.11
6b. 13.60 kg - Back	109.40	0.018	0.002	1.002	16.04	18.43	5.23	-0.08	2.00	0.12
7a. 6.80 kg - S-to-S	102.60	0.050	0.002	0.988	15.84	16.57	3.86	-0.07	1.24	0.11
7b. 13.60 kg - S-to-S	109.40	0.032	0.002	1.002	16.34	17.45	4.55	-0.08	1.67	0.12

Table 6

Inertial Properties for Male with PACKBOARD

	Loading Condition	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m^2)					
			X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1.	No added load	98.04	0.060	0.002	0.982	15.64	16.32	3.64	-0.08	0.90	0.05
2a.	6.80 kg – PTP	104.84	0.048	0.002	1.004	16.40	17.31	3.87	-0.09	1.32	0.06
2b.	13.60 kg – PTP	111.64	0.037	0.002	1.023	17.06	18.17	4.07	-0.09	1.68	0.06
3a.	6.80 kg – High	104.84	0.040	0.002	1.007	16.66	17.93	4.24	-0.09	1.68	0.06
3b.	13.60 kg – High	111.64	0.023	0.002	1.030	17.55	19.34	4.76	-0.09	2.36	0.07
4a.	6.80 kg – Low	104.84	0.040	0.002	0.979	15.65	16.93	4.24	-0.09	0.83	0.05
4b.	13.60 kg – Low	111.64	0.023	0.002	0.977	15.66	17.46	4.76	-0.09	0.76	0.05
5a.	6.80 kg – Front	104.84	0.048	0.002	0.993	15.85	16.76	3.87	-0.09	1.12	0.06
5b.	13.60 kg – Front	111.64	0.037	0.002	1.003	16.03	17.14	4.07	-0.09	1.31	0.06
6a.	6.80 kg – Back	104.84	0.033	0.002	0.993	15.85	17.66	4.77	-0.09	1.38	0.06
6b.	13.60 kg – Back	111.64	0.009	0.002	1.003	16.03	18.83	5.76	-0.09	1.81	0.06
7a.	6.80 kg – S-to-S	104.84	0.040	0.002	0.993	16.08	17.12	4.47	-0.09	1.25	0.06
7b.	13.60 kg – S-to-S	111.64	0.023	0.002	1.003	16.49	17.82	5.22	-0.09	1.56	0.06

Table 7

Inertial Properties for Female with ALICE LC-2

	Loading Condition	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m^2)					
			X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1.	No added load	85.96	0.040	0.003	0.922	11.70	12.84	3.60	-0.09	0.67	-0.05
2a.	6.80 kg – PTP	92.76	0.027	0.003	0.944	12.30	13.65	3.60	-0.10	1.20	-0.05
2b.	13.60 kg – PTP	99.56	0.016	0.003	0.964	12.82	14.34	3.98	-0.10	1.33	-0.04
3a.	6.80 kg – High	92.76	0.015	0.003	0.948	12.52	14.39	4.33	-0.10	1.45	-0.04
3b.	13.60 kg – High	99.56	-0.006	0.003	0.971	13.23	15.72	4.96	-0.10	2.11	-0.04
4a.	6.80 kg – Low	92.76	0.015	0.003	0.918	11.71	13.58	4.33	-0.10	0.57	-0.05
4b.	13.60 kg – Low	99.56	-0.006	0.003	0.915	11.73	14.22	4.96	-0.10	0.48	-0.05
5a.	6.80 kg – Front	92.76	0.027	0.003	0.933	11.85	13.20	3.80	-0.10	0.85	-0.05
5b.	13.60 kg – Front	99.56	0.016	0.003	0.943	11.99	13.51	3.98	-0.10	1.00	-0.05
6a.	6.80 kg – Back	92.76	0.004	0.003	0.933	11.85	14.57	5.17	-0.10	1.17	-0.05
6b.	13.60 kg – Back	99.56	-0.028	0.003	0.943	11.99	16.06	6.54	-0.10	1.59	-0.05
7a.	6.80 kg – S-to-S	92.76	0.015	0.003	0.933	12.08	13.72	4.56	-0.10	0.01	-0.05
7b.	13.60 kg – S-to-S	99.56	-0.006	0.003	0.943	12.45	14.49	5.42	-0.10	1.30	-0.05

Table 8

Inertial Properties for Female with ALICE LC-1

Loading Condition	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m^2)					
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1. No added load	85.54	0.042	0.003	0.920	11.67	12.74	3.57	-0.08	0.64	-0.03
2a. 6.80 kg – PTP	92.34	0.029	0.003	0.943	12.27	13.56	3.78	-0.09	1.00	-0.03
2b. 13.60 kg – PTP	99.14	0.017	0.003	0.963	12.80	14.26	3.96	-0.09	1.30	-0.02
3a. 6.80 kg – High	92.34	0.017	0.003	0.947	12.49	14.28	4.29	-0.09	1.41	-0.03
3b. 13.60 kg – High	99.14	-0.004	0.003	0.970	13.20	15.61	4.91	-0.10	2.07	-0.02
4a. 6.80 kg – Low	92.34	0.017	0.003	0.917	11.68	13.47	4.29	-0.09	0.54	-0.03
4b. 13.60 kg – Low	99.14	-0.004	0.003	0.914	11.69	14.10	4.91	-0.10	0.46	-0.03
5a. 6.80 kg – Front	92.34	0.029	0.003	0.932	11.82	13.11	3.78	-0.09	0.82	-0.03
5b. 13.60 kg – Front	99.14	0.017	0.003	0.942	11.96	13.42	3.96	-0.09	0.98	-0.03
6a. 6.80 kg – Back	92.34	0.006	0.003	0.932	11.82	14.43	5.11	-0.09	1.13	-0.03
6b. 13.60 kg – Back	99.14	-0.026	0.003	0.942	11.96	15.89	6.43	-0.10	1.56	-0.03
7a. 6.80 kg – S-to-S	92.34	0.017	0.003	0.932	12.05	13.62	4.52	-0.09	0.98	-0.03
7b. 13.60 kg – S-to-S	99.14	-0.004	0.003	0.942	12.42	14.37	5.37	-0.10	1.27	-0.03

25

Table 9

Inertial Properties for Female with LOCO

Loading Condition	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m^2)					
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1. No added load	84.08	0.059	0.003	0.910	11.53	11.77	2.74	-0.08	0.59	0.11
2a. 6.80 kg – PTP	90.88	0.045	0.003	0.940	12.52	12.98	2.96	-0.08	1.05	0.12
2b. 13.60 kg – PTP	97.68	0.033	0.003	0.966	13.38	14.02	3.15	-0.08	1.46	0.12
3a. 6.80 kg – High	90.88	0.037	0.003	0.945	12.86	13.66	3.30	-0.08	1.45	0.12
3b. 13.60 kg – High	97.68	0.018	0.003	0.974	14.01	15.29	3.79	-0.09	2.20	0.13
4a. 6.80 kg – Low	90.88	0.037	0.003	0.907	11.55	12.35	3.30	-0.08	0.50	0.11
4b. 13.60 kg – Low	97.68	0.018	0.003	0.904	11.56	12.84	3.79	-0.09	0.43	0.10
5a. 6.80 kg – Front	90.88	0.045	0.003	0.926	11.81	12.26	2.96	-0.08	0.83	0.11
5b. 13.60 kg – Front	97.68	0.033	0.003	0.939	12.04	12.68	3.15	-0.08	1.04	0.12
6a. 6.80 kg – Back	90.88	0.028	0.003	0.926	11.81	13.10	3.80	-9.08	1.12	0.11
6b. 13.60 kg – Back	97.68	0.002	0.003	0.939	12.04	14.25	4.72	-0.09	1.59	0.12
7a. 6.80 kg – S-to-S	90.88	0.037	0.003	0.926	11.96	12.60	3.45	-0.08	0.98	0.11
7b. 13.60 kg – S-to-S	97.68	0.018	0.003	0.939	12.34	13.32	4.08	-0.09	1.32	0.12

Table 10

Inertial Properties for Female with PACKBOARD

Loading Condition	System Mass (kg)	System Center of Mass (m)			System Inertia Tensor (kg m^2)					
		X	Y	Z	I_{XX}	I_{YY}	I_{ZZ}	I_{XY}	I_{XZ}	I_{YZ}
1. No added load	86.32	0.048	0.003	0.921	11.80	12.43	3.26	-0.09	0.69	0.05
2a. 6.80 kg – PTP	93.12	0.035	0.003	0.943	12.38	13.20	3.45	-0.10	1.02	0.06
2b. 13.60 kg – PTP	99.92	0.024	0.003	0.962	12.87	13.87	3.62	-0.10	1.32	0.06
3a. 6.80 kg – High	93.12	0.026	0.003	0.947	12.60	13.77	3.80	-0.10	1.35	0.06
3b. 13.60 kg – High	99.92	0.008	0.003	0.969	13.30	14.93	4.26	-0.10	1.92	0.07
4a. 6.80 kg – Low	93.12	0.026	0.003	0.915	11.84	13.01	3.80	-0.10	0.54	0.05
4b. 13.60 kg – Low	99.92	0.008	0.003	0.910	11.88	13.52	4.26	-0.10	0.41	0.05
5a. 6.80 kg – Front	93.12	0.035	0.003	0.931	11.92	12.74	3.45	-0.10	0.84	0.05
5b. 13.60 kg – Front	99.92	0.024	0.003	0.939	12.02	13.02	3.62	-0.10	0.98	0.06
6a. 6.80 kg – Back	93.12	0.018	0.003	0.931	11.92	13.60	4.31	-0.10	1.04	0.05
6b. 13.60 kg – Back	99.92	-0.008	0.003	0.939	12.02	14.61	5.22	-0.11	1.35	0.06
7a. 6.80 kg – S-to-S	93.12	0.026	0.003	0.931	12.15	13.09	4.03	-0.10	0.94	0.05
7b. 13.60 kg – S-to-S	99.92	0.008	0.003	0.939	12.48	13.66	4.72	-0.10	1.16	0.06

component for the female was shifted slightly more toward the backpack than for the male. This is due to the greater mass of the pack relative to total body mass for the female. This result indicates that a female may have to make greater adjustments in posture than a male in order to balance the pack and load. This is supported by the results of the study of walking which showed that females demonstrated more forward leaning than males (Ref. 9).

Backpacks

Again using comparisons of data from Tables 3 to 10, some general trends present for the packs can be identified. The total system mass is nearly _dentical for all backpacks with the exception of the LOCO. Under the conditions in which the LOCO was included, the total system mass was slightly less than that for the other three packs. This means that there is slightly less resistance to linear acceleration under the LOCO conditions. Consequently, in this sense, it would be advantageous to the carrier to use the LOCO. This advantage, however, is quite small.

In terms of the moments of inertia, the results vary somewhat depending on the load and load position used. The results for the ALICE LC-1 and ALICE LC-2 were nearly identical for all conditions. This was expected since the packs are identical and the frames are of similar dimensions. In general, the LOCO demonstrated greater moments of inertia about the X axis than the other three packs. Because of its greater length, this was expected. This result, however, is not terribly important because rotations about his dorso-ventral axis are not regular occurrences. Much more common are rotations about the transverse (e.g. hitting the dirt) and longitudinal (e.g. a change in direction) axes. For the transverse or Y axis, the LOCO and PACKBOARD appear to be slightly advantageous over the ALICE LC-1 and ALICE LC-2. Because of its relatively greater length, one may at first question this result for the LOCO pack. It is important, however, to remember that the moment of inertia is dependent upon mass as well as the distribution of the mass. Even though the LOCO's greater length would tend to add to moment of inertia about the Y axis, its smaller mass tends to compensate for this. This was not shown to be true, however, for the X axis. For the longitudinal (Z) axis, the LOCO and PACKBOARD demonstrate smaller moments of inertia than the ALICE LC-1 and ALICE LC-2. This is particularly true for the LOCO. Not only does it have a smaller mass, it also is positioned closer to the body and has a smaller depth dimension than the ALICE LC-1 and ALICE LC-2.

In terms of the location of the center of mass, the LOCO appears to be slightly better than the other backpacks. The LOCO results in a smaller shift in the direction of the pack along the dorso-ventral (X) axis and in a lower center of mass location along the longitudinal (Z) axis. No differences existed between backpacks for the transverse (Y) axis. The combination of these results suggests that a slightly more stable position results when the LOCO is worn. Again, it is important to caution the reader that all of these differences are rather small and may be of limited practical importance.

Added Loads

The influence of added load is quite simple to expalin. For a given gender, backpack, and load position, added load resulted in an increased total system mass, increased moment of inertia values for each of the three

axes, and a shift in the center of mass in the direction of the added load. This is exactly as was expected and indicates that resistance to acceleration decreases as the load is decreased. In other words, for maximum movement efficiency, the smallest possible load should be carried.

Loading Configurations

Unique to this phase of the contract was an examination of load configurations. In the studies of load carrying performance of men and women (Refs. 7, 8, 9), loads added to the packs were added in only one position, (PTP). Additional loading positions were examined in this study. These included positioning the load high, low, front (close to the body), back (away from the body), and side-to-side (S-to-S).

In terms of the dorso-ventral (X) component of the center of mass, the PTP and front loadings created the smallest shift in the direction of the pack. In both cases the load was positioned close to the body. As one might quickly surmise, the greatest shift resulted when the loading was in the back positioning. These results parallel those for moment of inertia about the longitudinal (Z) axis. Because the mass was distributed closer to this axis, the front and PTP loadings were best while the back loading was the poorest.

Perhaps the most significant differences between the loading configurations were noted for the Z-component of the center of mass and the moments of inertia about the dorso-ventral (X) and transverse (Y) axes. The optimal loading position was found to be the low condition. This not only led to a more stable (lower) Z component but also to smaller moments of inertia about the X and Y axes. In general, the poorest loading condition in terms of the Z component and XX and YY moments of inertia about the dorso-ventral and transverse axes was found to be the high condition.

Products of Inertia

Thus far little has been mentioned about the products of inertia resulting from the different loading configurations. These results are not the most important for this model, but do provide some useful information. In general, the presence of a non-zero product of inertia indicates that some asymmetry was present in the loading. For the loading configurations used in this project, the XZ plane was quite close to being a plane of symmetry for all configurations. When this is the case, the I_{XY} and I_{YZ} products of inertia are nearly zero. This situation was confirmed by the small products of inertia for the X and Y axes (I_{XY}) and the Y and Z axes (I_{YZ}), respectively. The third product of inertia (I_{XZ}), however, was considerably larger than the other two and represents an asymmetrical loading with respect to the X and Z axes. For example, when the load was in the back position, there was no counterbalancing load on the opposite side of either the X or the Z axis. This resulted in a significant product of inertia for the X and Z axes. The larger values for the I_{XZ} products of inertia found in this study confirm this. Even these values were relatively small and do not indicate extreme shifts of the principal axes away from the fixed axes used in this analysis.

SUMMARY AND CONCLUSIONS

In general, the results of this phase of the project confirmed the speculations of Hinrichs, Lallemant, and Nelson (Ref. 2). The results demonstrated that the most desirable loading condition is one in which the carried mass is as small as possible and is positioned as low and close to the body as possible. Loading conditions to be avoided are those in which the load is relatively high and far from the body.

In conclusion, computer modeling appears to be a very useful tool for examining selected characteristics of load carrying behavior. The most difficult stage in the modeling process is the development of a simple, but accurate and adaptable, model. Once this has been accomplished, many different conditions can be examined at a much lower cost and with much less effort than could be accomplished through experimentation. This is not to suggest that modeling is appropriate for all situations. It can, however, be a useful tool to the researcher.

Recommendations for Further Study

A logical extension of this work would be examination of other loading conditions which may be encountered in a real situation. For example, it may not be feasible to position all added loads in a symmetrical fashion. If this is the case a probable loading condition can be easily simulated using the computer model. In addition, it may be useful to develop a more refined model of the backpack and the individual components which commonly make up the carried load. Such a model would allow the researcher the opportunity to examine many different loading conditions to gain greater insight into the optimal loading of a pack. Obviously, this must be done with some knowledge of what is needed in the field. In other words, if modeling suggested that a particular component should be loaded in the bottom of the pack because of its inertial characteristics, but that component is used quite frequently, it would be inappropriate to suggest loading that component in any position other than an accessible one. Such a situation, however, may well suggest the need for a multicomponent pack bag such that both optimal positioning and easy accessibility can be achieved. Modeling would be an ideal tool to examine such a question. Finally, inertial property modeling should be extended to include activities a soldier performs while carrying a pack.

CITED REFERENCES

1. Olinick, M. _An Introduction to Mathematical Models in the Social and Life Sciences_. Reading, Massachusetts: Addison Wesley Publishing Company, 1978.

2. Hinrichs, R.N., S.R. Lallemant, and R.C. Nelson. _An Investigation of the Inertial Properties of Backpacks Loaded in Various Configurations_ (Tech. Rep. NATICK/TR-82/023). Natick, Massachusetts: US Army Natick Research and Development Laboratories, May 1982.

3. White, R.M. and E. Churchill. _The Body Size of Soldiers: US Army Anthropometry - 1966_ (Tech. Rep. 72-51-CE). Natick, Massachusetts: United States Army Natick Laboratories, December 1971.

4. Churchill, E., T. Churchill, J.T. McConville, and R.W. White. _Anthropometry of Women of the US Army - 1977_ (Tech. Rep. NATICK/TR-77/024). Natick, Massachusetts: United States Army Natick Research and Development Command, June 1977.

5. Hanavan, E.P. _A Mathematical Model of the Human Body_. (Tech. Rep. AMRL-TR-640102). Wright-Patterson Air Force Base, Ohio: Aerospace Medical Research Laboratories, 1964.

6. Hinrichs, R.N. "Princiapal Axes and Moments of Inertia of the Human Body: An Investigation of the Stability of Rotary Motions". Unpublished Masters Thesis, University of Iowa, Iowa City, Iowa, 1978.

7. Nelson, R.C. and P.E. Martin. _Volume I. Effects of Gender and Load on Combative Movement Performance_ (Tech. Rep. NATICK/TR-82/011). Natick, Massachusetts: US Army Natick Research and Development Laboratories, February 1982.

8. Nelson, R.C. and P.E. Martin. _Volume I. Effects of Gender, Load, and Backpack on Easy Standing and Vertical Jump Performance_ (Tech. Rep. NATICK/TR-82/016). Natick, Massachusetts: US Army Natick Research and Development Laboratories, March 1982.

9. Martin, P.E. and R.C. Nelson. _Volume III. Effects of Gender, Load, and Backpack on the Temporal and Kinematic Characteristics of Walking Gait_ (Tech. Rep. NATICK/TR-82/021). Natick, Massachusetts: US Army Natick Research and Development Laboratories, April 1982.

10. _The International Mathematical and Statistical Library of Subprograms_, Edition 8. University Park, PA: The Pennsylvania State University Computation Center, 1980.

SUPPLEMENTAL REFERENCES

Beer, F.P., and E.R. Johnston, Jr. _Vector Mechanics for Engineers: Statics and Dynamics_, 3rd Ed. New York: McGraw-Hill, 1977.

Greenwood, D.T. Principles of Dynamics. Englewood Cliffs, New
Jersey: Prentice Hall, Inc., 1965.

IMSL Library Reference Manual. Volume 1 (Chapters A to E). Houston,
Texas: IMSL, Inc., 1979.

Synge, J.L. and B.A. Griffith. Principles of Mechanics. New York:
McGraw-Hill, 1942.

APPENDIX A

Clothing and Equipment Used in This Study

Clothing, Body Armor, and Sleeping Gear

The items considered in this model, either as components of the pack load or as gear worn by the load carrier, are standard products from the Army's inventory. The Army nomenclature for each item and its military specification, which contains a description of the item, are listed below.

Nomenclature	Specification
Socks, Wool, Cushion Sole	MIL-S-48
Boot, Combat, Leather, Black, Direct Molded Sole	MIL-B-43481E
Shirt, Utility, Durable Press	MIL-S-43929B
Trousers, Utility, Durable Press	MIL-T-43932C
Undershirt, Cotton, White	JJ-U-513D
Helmet, Personnel Armor System Ground Troops (PASGT)	LP/P DES 12-78A
Sleeping Bag, Intermediate Cold, Synthetic Fill	MIL-S-44016
Mattress, Pneumatic, Insulated	MIL-M-43968
Bag, Waterproof, Clothing	MIL-B-3108
Poncho, Wet Weather	MIL-P-43700

Load Carrying Equipment

In the Army, all items worn or carried by the soldier are divided into two categories, a fighting load and an existence load. The former consists of items essential for the immediate mission, such as the clothing and armor being worn, a rifle, ammunition, and a canteen. The existence load consists of items needed to sustain the soldier in the field for a period of time, such as sleeping gear, rations, and additional clothing. Carrying equipment has been developed to accommodate some of the items comprising the fighting and the existence loads. The load carrying gear which was included in the present study is described below.

Fighting Gear (Figure A-1)

This standard Army equipment consists of a belt and suspenders, made of nylon webbing and nylon duck, to which other items are attached by means of slide keepers. The equipment hung on the belt includes:

a. a cover made of nylon duck that holds a steel cup with a .9-liter capacity and a .9-liter canteen for water.

b. a plastic case that holds a folding intrenching tool.

c. two cases made of nylon duck which hold ammunition rounds and also have straps from which grenades can be hung.

d. a small pouch for first aid dressings or a compass.

The Army nomenclature and military specification for each component of the fighting gear are listed below.

34
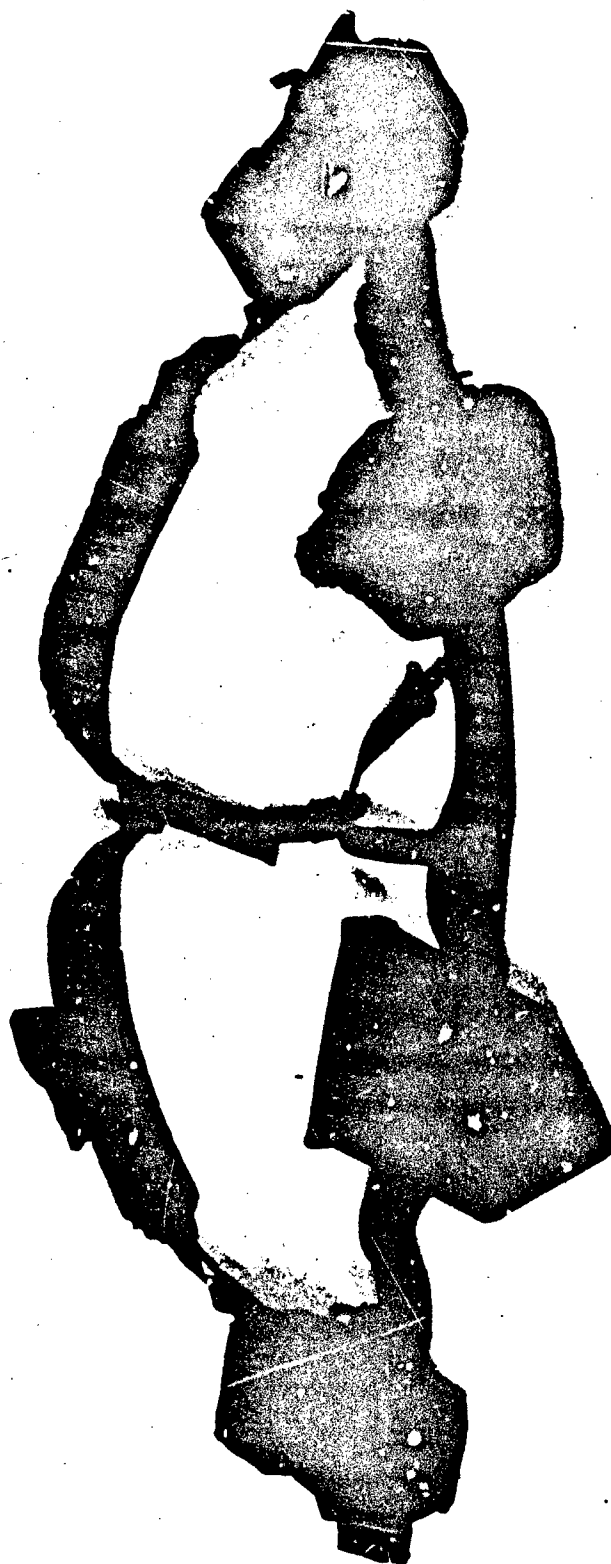
Figure A-1. ALICE Fighting Gear.

Nomenclature	Specification
Belt and Suspenders, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-B-43826 and MIL-S-43819
Canteen, Water, 1-Quart Capacity	MIL-C-43103
Cup, Water Canteen, Steel, 1-Quart	MIL-C-43761
Cover, Canteen	MIL-C-43742
Intrenching Tool, Folding, Lightweight	MIL-I-43684
Intrenching Tool Carrier	MIL-I-43831
Case, Small Arms, Ammo, 30-Round	MIL-C-43827
Case, First Aid/Compass	MIL-C-43745

Carrying Gear for Existence Load

Four pack and frame combinations were used in this study. They included standard Army, experimental, and commercial items. Three were backpacks with external frames (ALICE LC-1, ALICE LC-2, and PACKBOARD) and one was an internal-frame system (LOCO). The same pack was used on each of the external frames. These items are described below.

ALICE Pack (Figure A-2). This standard Army equipment is a component of a load carrying system designated as All-Purpose Lightweight Individual Carrying Equipment (ALICE). The ALICE pack is made of nylon duck and nylon webbing and weighs 1.3 kg. It has a large, top-loading, main compartment, an outside pocket on each of two sides and the front, and three smaller pockets above the center outside pocket. The maximum capacity of the pack is approximately 32 kg. The main compartment can be closed by means of a drawstring and is covered by a storm flap. The flap is secured by two, vertical straps which encircle the pack. Each outside pocket has a drawstring closure and is covered by a flap which is secured by a single strap. Strips of webbing sewn on the outside surface of the main compartment can be used for attaching items. A pocket large enough to accommodate a field radio is sewn inside the main compartment on the surface closest to the wearer's back. There are also "D" rings and tie strings inside the main compartment which can be used to shorten the pack if it is not filled to capacity. The pack is attached to a frame by means of an envelope at the top of the pack which slides over the top of the frame and a strap with a buckle on the bottom of each side of the pack which wraps around the frame.

ALICE LC-2 Frame (Figure A-3). This standard Army frame with its associated straps is also a component of the ALICE system and is used with the ALICE pack. It carries the designation "LC-2" to differentiate it from a frame (LC-1) which it replaced in the Army's inventory. The ALICE LC-2 frame is structured of aluminum tubing. It is 50.8 cm high and 31.1 cm wide. There are two, aluminum, horizontal members made from flat stock which extend from one side of the frame to the other and are riveted to the aluminum tubing. One, aluminum, vertical member, also made from flat stock, is riveted to the top and the bottom of the frame. Toward the top of the frame, this vertical piece and the aluminum tubing are angled toward the wearer's back. Two metal loops are attached to the top, horizontal, tubular portion of the frame. These are used to retain one end of the shoulder straps. There is also a grommet at the lower portion of each side of the frame through which the other end of each shoulder strap passes and is secured.

Figure A-2. ALICE Pack.
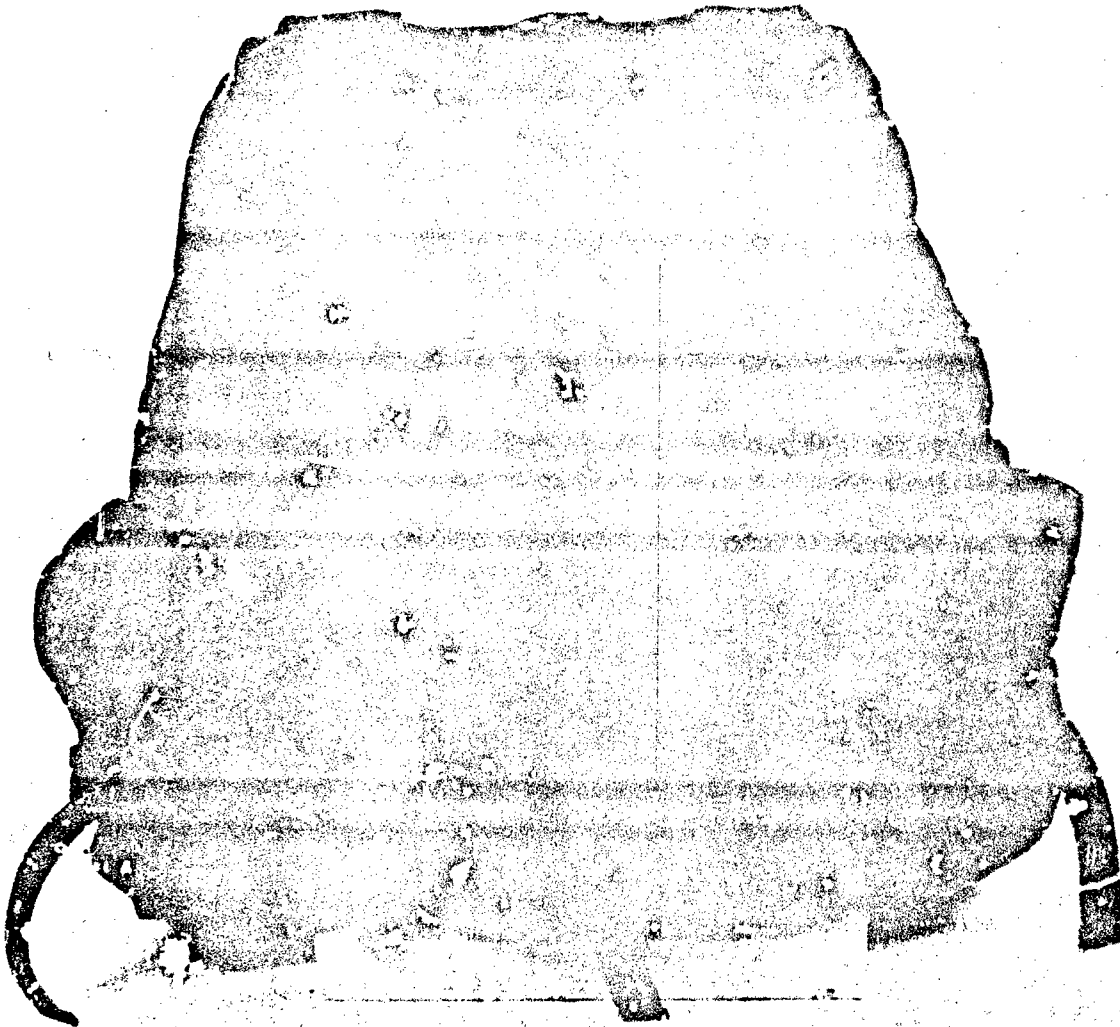
Figure A-2. ALICE Pack.
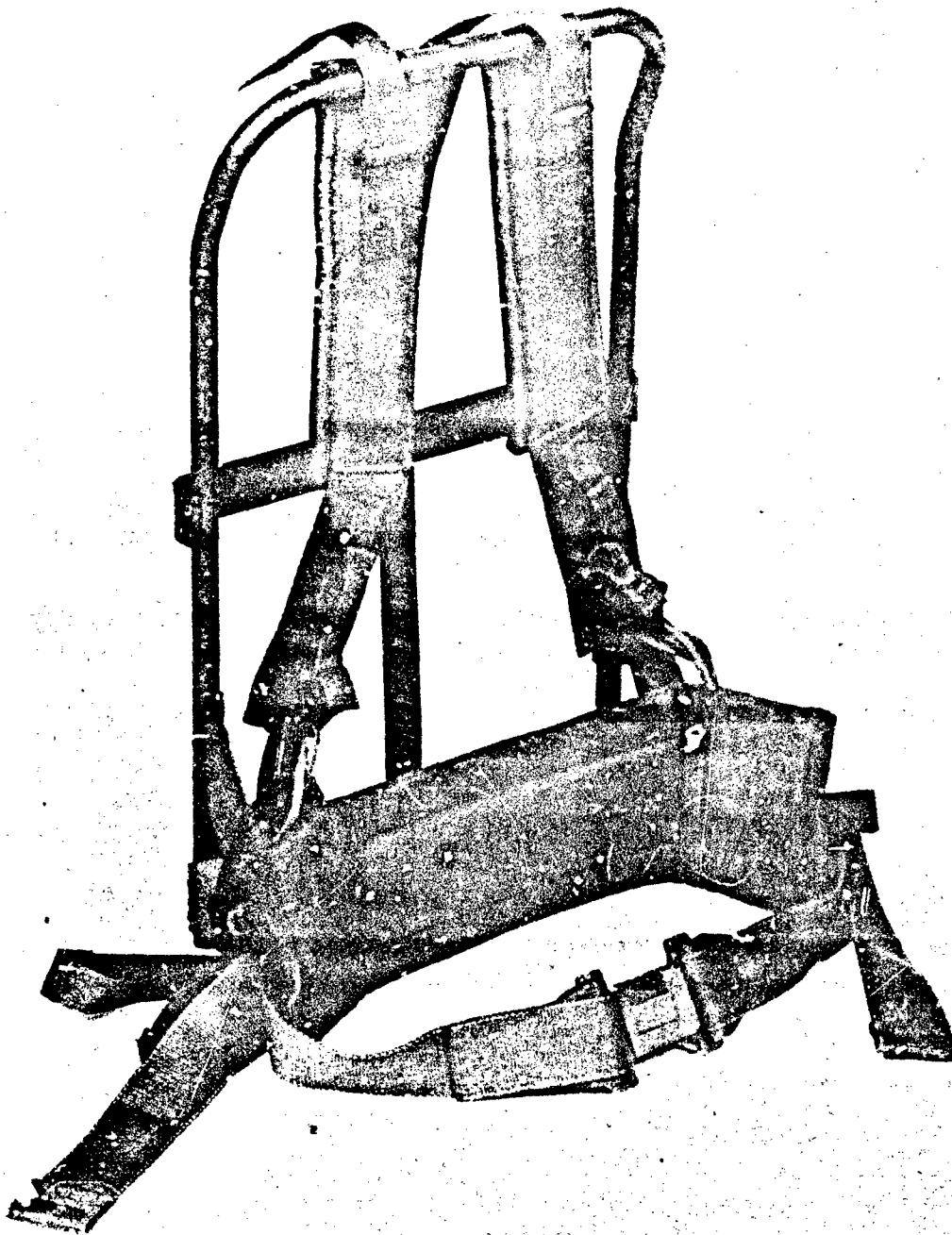
Figure A-3. ALICE LC-2 Frame.
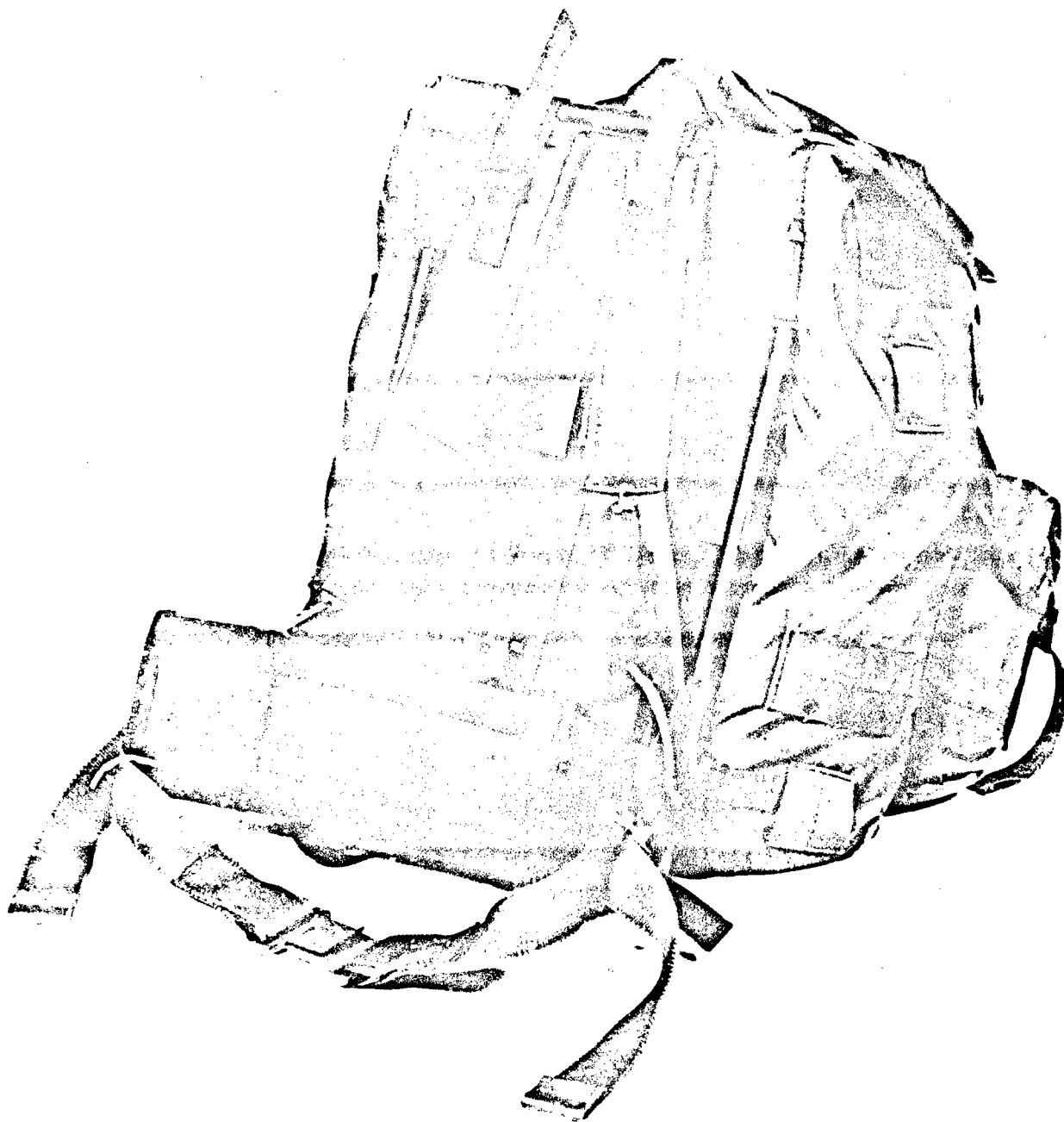
Figure A-3. ALICE LC-2 Frame.

At the top of each shoulder strap is a rectangular piece of foam spacer material, 22.9 cm long, 7.0 cm wide, and 1.3 cm thick, covered with nylon duck and nylon webbing. The remainder of the strap is unpadded, nylon webbing. A quick-release device and a buckle used for length adjustment are incorporated into each shoulder strap. The lower back strap, which is 43.8 cm long and 12.7 cm high, is also made of foam spacer material, 1.3 cm thick, covered with nylon duck. The back strap is secured to the frame by use of narrow webbing which passes through a buckle. The waist belt is comprised of two pieces of nylon webbing 4.4 cm wide. One end of each piece is sewn to the back strap. Each piece includes an adjustment mechanism used to shorten or lengthen the belt. The belt is secured around the waist by a plastic, quick-release device. The frame with its associated straps weighs 1.7 kg.

ALICE LC-1 Frame (Figure A-4). This was developed for use with the ALICE pack and was standard Army equipment prior to the introduction of the ALICE LC-2. The LC-1 and the LC-2 frames have the same dimensions and are of the same basic design. However, the materials used in their shoulder, waist, and back straps are different. The top portion of each shoulder strap, measuring 38.7 cm long and 6.4 cm wide, is made of a cloth spacer material covered with nylon duck and nylon webbing. The remainder of the strap is narrow nylon webbing. A quick-release device is incorporated into the left shoulder strap and both straps have buckles for length adjustments. The lower back strap, which is 34.3 cm long and 7.6 cm high, is also made of a cloth spacer material covered with nylon duck. The back strap is secured to the frame by use of webbing which is attached to a turnbuckle. The waist belt is made of two pieces of nylon webbing 2.5 cm wide. One end of each piece is wrapped around the lower, tubular portion of the frame. Each piece includes a buckle for adjusting the length of the belt. The belt is secured around the waist by a metal and plastic quick-release device. The frame with its associated straps weighs 1.4 kg.

PACKBOARD (Figure A-5). This experimental equipment, fabricated for the study, is made from flat aluminum stock. The PACKBOARD is 54.6 cm high and measures 34.9 cm across at its widest point. It accommodates the ALICE pack. Two horizontal slits were cut in the aluminum at the top of the PACKBOARD for attachment of the shoulder straps. Two vertical slits were cut on each side toward the bottom for attachment of the lower back strap and the straps on the ALICE pack. There are two additional openings in this area for securing the bottom ends of the shoulder straps to the PACKBOARD. The shoulder, waist, and back straps are the same ones used with the ALICE LC-2 frame. A flat, rectangular pad of foam spacer material, 29.2 cm high, 25.4 cm wide, and 1.3 cm thick, is attached to the PACKBOARD directly above the backstrap and covered with nylon duck. The PACKBOARD and associated straps weigh 2.3 kg.

LOCO (Figure A-6). This system is manufactured by Lowe Alpine Systems/ International Equipment Manufacturing. It is a top-loading, internal-frame backpack. The frame consists of two, vertical, aluminum stays which extend the length of the pack, a distance of 59.7 cm. The stays can be removed from their pockets, which are sewn to the outside surface of the pack, and are flexible enough to be bent by hand. The stay pockets are 7.6 cm apart. The pack is constructed of pack cloth. It has a large main compartment with a pocket sewn inside on the
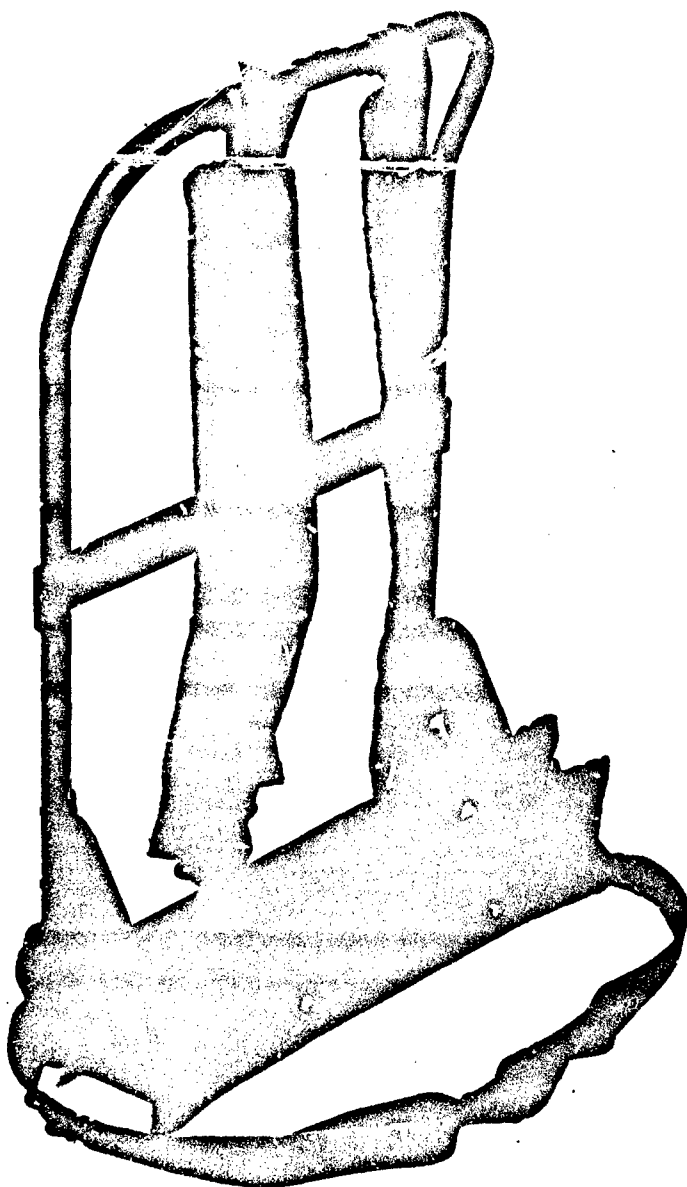
Figure A-4. ALICE LC-1 Frame.

Figure A-4. ALICE LC-1 Frame.
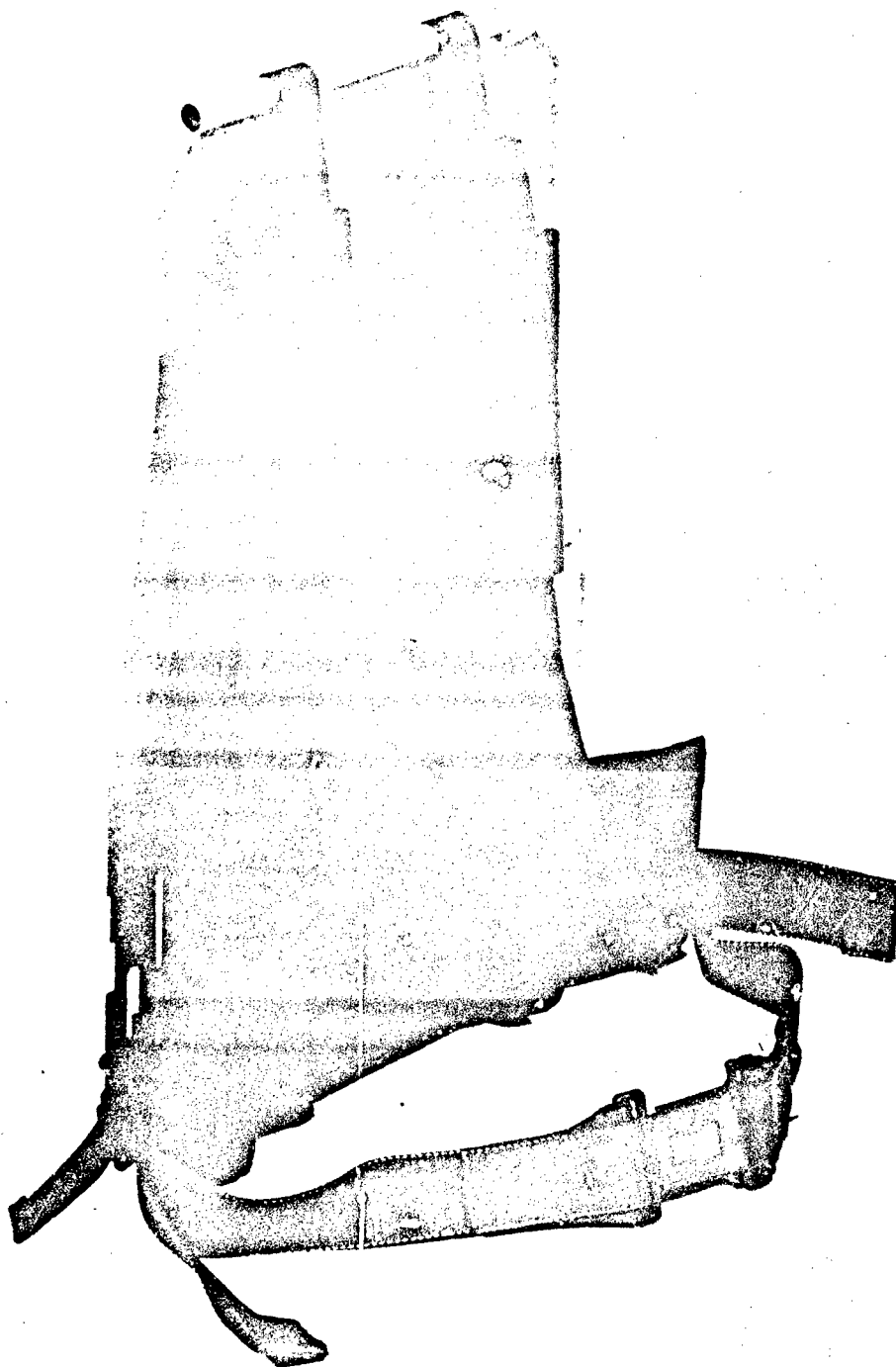
Figure A-5. PACKBOARD.

Figure A-5. PACKBOARD.
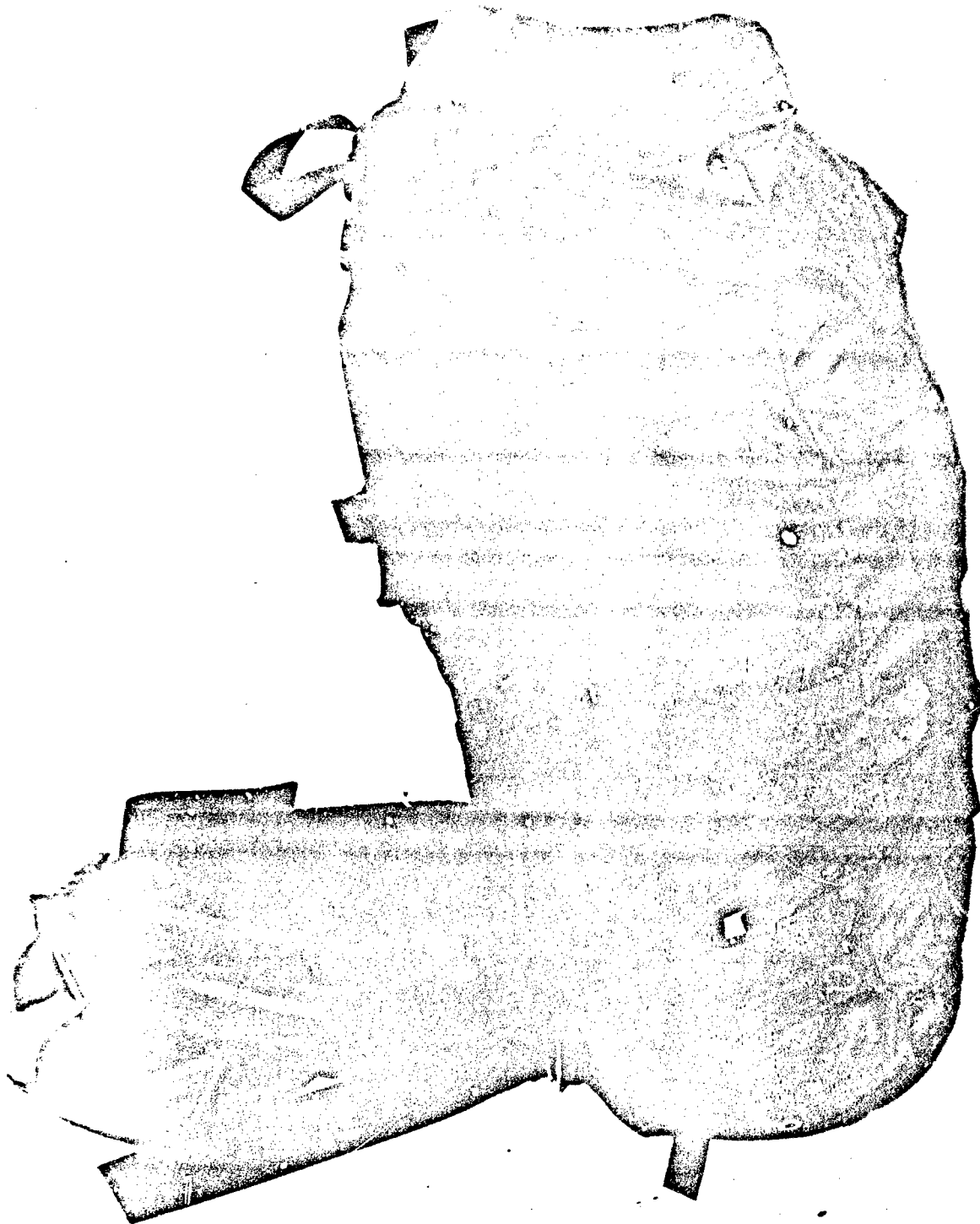
Figure A-6.   LOCO

Figure A-6.   LOCO

47
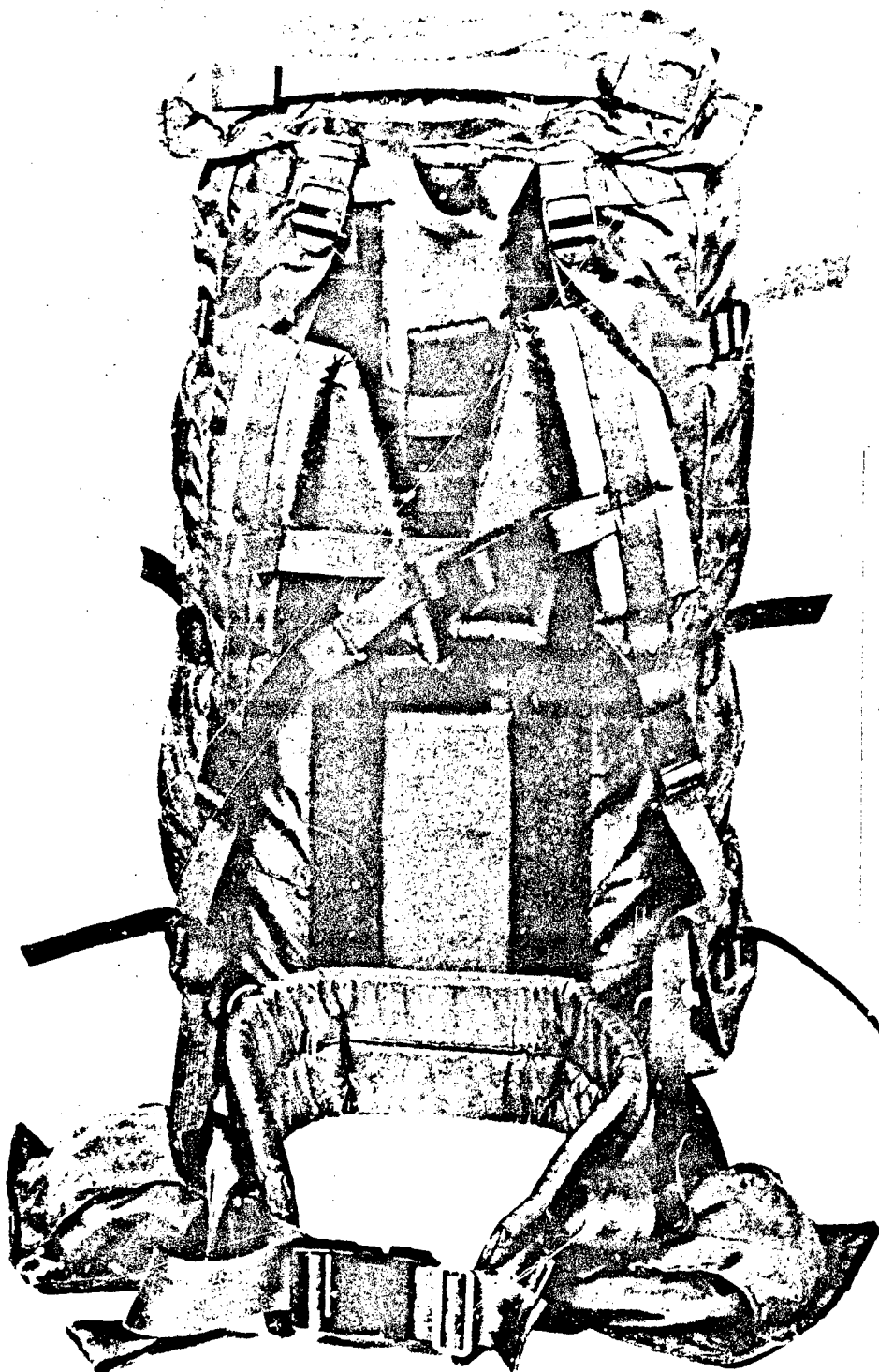
surface closest to the wearer's back. The main compartment can be closed by means of a drawstring and is covered by a storm flap which has an outside, zippered pocket. The flap is secured by two vertical straps and buckles. There are three, horizontal straps made of nylon webbing which extend along each side of the pack. The pack can be compressed by use of buckles attached to the straps. A foam pad, 17.8 cm high, 7.6 cm wide, and .6 cm thick, is attached to the center, lower portion of the pack, between the stays of the frame.

The foam-padded portion of each shoulder strap is 39.4 cm long, 6.4 cm wide, and 1.3 cm thick. The remainder of the shoulder strap is made of unpadded nylon webbing. The straps are designed such that the padding extends over the shoulders. Each strap is attached to the pack at three points. A strip of webbing, with a buckle for length adjustments, extends from the middle of the padded section on each strap to the top of the pack. Another strip, with a combined quick-release and length-adjustment device, extends from the bottom edge of each shoulder strap's padded section to the bottom of the pack. The third attachment point is at the center of the pack, a location approximating the center of the wearer's back. Here, the ends of both shoulder straps are sewn to a nylon webbing strap. The point at which the strap attaches to the pack can be adjusted by use of a vertical ladder of webbing. A sternum strap with a quick-release and length-adjustment buckle extends from one shoulder strap to the other.

The foam-padded waist belt is 77.5 cm long, 10.2 cm high, and 1.3 cm thick. It is covered with pack cloth. Nylon webbing is sewn to the outside surface of the belt. The waist belt is attached to the bottom of the pack at two points (each is at the outside edge of a frame stay pocket) by means of the webbing on the belt, metal pins, and buckles. The belt is secured around the waist with a plastic, quick-release device and webbing straps which can be adjusted to accommodate a range of waist circumferences. The weight of the LOCO, including the pack, frame stays, and straps, is 1.4 kg.

The nomenclature and military specification for each pack and frame included in this study which is or was in the Army's inventory are listed below.

Nomenclature	Specification
Field Pack, Nylon, Large, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-F-43832
Straps, Pack Frame and Strap/Frame Assembly, LC-2, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-S-43835
Frame Pack with Straps, LC-1, All-Purpose Lightweight Individual Carrying Equipment (ALICE)	MIL-F-43834

APPENDIX B

IMSL Policy Statement

The following statement appears in the Penn State Computation Center
write-up IMSL[10] and contains a statement regarding the IMSL policies on
acknowledging and exporting IMSL Subroutines:

Written works utilizing computer output or results of computational algorithms
involving the IMSL subroutine library should properly cite the IMSL Reference
Manual. Computer programs that utilize IMSL subprograms may be published and
exported in accordance with IMSL Subscription Policies:

> "Title to the library products under this subscription
> remains with IMSL. Modification of the library products
> by the subscriber is allowed, but such changes do not
> affect IMSL's title in the products."

> "Arrangements with IMSL must be made if application
> programs containing embedded object form IMSL Library
> routines are to be distributed outside the subscribing
> organization. In general, IMSL has the intent of being
> agreeable in this case if the application of programs
> are to be made available at no charge. If the
> application programs are to be made available for a
> charge, financial arrangements must be made with IMSL.
> When IMSL library routines are utilized in research work
> and resulting publications require, in the opinion of
> the author, the reproduction of listings of pertinent
> library source code in the research publication, IMSL
> requests reference, and grants permission. Where the
> program documentation only would be sufficient, IMSL
> encourages that mode of usage. When application
> programs, developed as a by-product of research work,
> contain embedded library routines, these application
> programs may be taken, as is, by the authors on their
> departure from the research institution for internal
> usage in their new locations. IMSL's only restriction
> is that any embedded library routines be used only as
> originally incorporated in the application program, and
> not removed for usage in any other software development."

---

[10] _The International Mathematical and Statistical Library of Subprograms_,
Edition 8. University Park, PA: The Pennsylvania State Computation Center,
1980, p. 10.

APPENDIX C

The Biomechanics of Load Carrying Behavior:
System Inertial Characteristics -- 3D Program

This appendix contains a listing of the control cards (input data deck) for the male and the female models and the source listing of the computer program. As one can quickly see when examining the control cards, the conditions of the model are easily varied by changing only a few cards. Cards 1 and 2 provide no information to vary the model, but allow the user to control the number of different conditions to be examined in one computer run and to describe the various conditions used. On card 3, the user must specify whether the model is for a male or a female and the backpack to be examined. This is the first of four cards which control the various combinations examined in this project. Cards 45, 46, and 47 are the other three of concern and allow the user to control the magnitude and positioning of one or two added loads to the pack. On card 45, the user must specify the magnitude of the desired loads and then indicate their locations using cards 46 and 47. Consequently, variations in only four of the 51 cards of the control deck are responsible for the many variations examined in this project.

When specifying the magnitude of the added loads for a particular pack, the user is limited only by the format statement used to read the information into the model. The maximum value for each load, therefore, is 99.99 kg which would form a total load well beyond the range typically used in the military. As far as the positioning of the loads is concerned, the only limitation is that the load must be placed somewhere within the pack since the load is positioned as proportions of the three pack dimensions. Consequently, card 46 would contain the proportions of the dorso-ventral, transverse, and longitudinal dimensions of the pack for load 1 and card 47 would contain the same information for load 2. One can see that the user has the option of examining almost any special pack loading. This illustrates the major flexibility of this program.

The model does not, however, allow the user to examine the inertial properties of the system by using a model of a male or a female of other than the 50th percentile in stature and body mass. Both the male and the female models were constructed using 50th percentile data and were assumed to be fixed. In order to incorporate other body percentiles, one would need to change a number of control cards. Values for stature and mass (cards 4(1), 48), various body coordinate points (cards 17-26), and coordinates used to position the rifle (cards 49-51) would all be affected by a change in the percentile used for the male or the female model. Given appropriate anthropometric characteristics for other percentiles, however, the user could develop other male and female models and thereby maximize the flexibility of the computer model. Although the incorporation of different percentiles may have some value in some future work, it was considered to be beyond the scope of this project.

INPUT DATA DECK

Card No.	Variable name	Format	Values Male	Values Female
1	NCOND	I2	Set by user	
2	HEAD	50A1	Description of run supplied by user	
3	NSEX,NPACK	2I1	Both are set by user	
4	SMASS (segments 1-9)	9F6.3	(1) 72.655 (2) 1.468 (3) 1.198 (4) 1.755 (5) 1.755 (6) 1.264 (7) 0.852 (8) 0.852 (9) 3.370	61.208 1.468 1.198 1.755 1.755 1.264 0.718 0.718 3.370
5	SEGMIL (segments 1-9)	9F7.4	(1) 1.0710 (2) 0.0 (3) 0.0 (4) 0.0 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.0068	1.0710 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.0068
6	SEGMIT (segments 1-9)	9F7.4	(1) 11.7840 (2) 0.0 (3) 0.0 (4) 0.0 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.2120	11.7840 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.2120
7	SEGMID (segments 1-9)	9F7.4	(1) 12.2450 (2) 0.0 (3) 0.0 (4) 0.0 (5) 0.0 (6) 0.0 (7) 0.0 (8) 0.0 (9) 0.2179	12.2450 0.0 0.0 0.0 0.0 0.0 0.0 0.0 0.2179

Card No.	Variable name	Format			Values Male	Female
8	PRODIN (Body)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
9	PRODIN (Helmet)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
10	PRODIN (FG1)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
11	PRODIN (FG2)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
12	PRODIN(FG3)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
13	PRODIN (FG4)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
14	PRODIN (L.Boot)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
15	PRODIN (R.Boot)	3F7.4		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	0.0	0.0
16	PRODIN (Rifle)	3F7.4		(1)	0.0017	0.0017
				(2)	0.0041	0.0041
				(3)	-0.0029	-0.0029
17	COO (Body)	3F6.3		(1)	0.094	0.088
				(2)	0.0	0.0
				(3)	0.959	0.901
18	COO (Helmet)	3F6.3		(1)	0.0	0.0
				(2)	0.0	0.0
				(3)	1.679	1.563

54

Card No.	Variable name	Format		Values Male	Female
19	COO(FG1)	3F6.3	(1)	0.0	0.0
			(2)	0.205	0.215
			(3)	0.917	0.836
20	COO(FG2)	3F6.3	(1)	0.175	0.130
			(2)	0.125	0.125
			(3)	0.917	0.836
21	COO(FG3)	3F6.3	(1)	0.175	0.130
			(2)	−0.125	−0.125
			(3)	0.917	0.836
22	COO(FG4)	3F6.3	(1)	0.0	0.0
			(2)	−0.205	−0.215
			(3)	0.917	0.836
23	COO(L.Boot)	3F6.3	(1)	0.120	0.109
			(2)	0.165	0.176
			(3)	0.0	0.0
24	COO(R.Boot)	3F6.3	(1)	0.120	0.109
			(2)	−0.165	−0.176
			(3)	0.0	0.0
25	COO(Rifle)	3F6.3	(1)	0.384	0.347
			(2)	0.074	0.090
			(3)	1.067	0.998
26	SHOUL	6F6.3	(1)	0.0	0.0
			(2)	0.226	0.210
			(3)	1.436	1.333
			(4)	0.0	0.0
			(5)	−0.226	−0.210
			(6)	1.436	1.333
27	CF	12F6.3	(1)	0.100	0.100
			(2)	0.0	0.0
			(3)	0.0	0.0
			(4)	0.100	0.100
			(5)	0.0	0.0
			(6)	0.0	0.0
			(7)	0.100	0.100
			(8)	0.0	0.0
			(9)	0.100	0.100
			(10)	0.100	0.100
			(11)	0.0	0.0
			(12)	0.0	0.0

Card No.	Variable name	Format	Values		
				Male	Female
28	PKMASS	4F5.2	(1) (2) (3) (4)	12.51 12.09 10.63 12.87	12.51 12.09 10.63 12.87
29	PKMI (ALICE LC-2)	3F5.3	(1) (2) (3)	0.447 0.354 0.351	0.447 0.354 0.351
30	PKMI (ALICE LC-1)	3F5.3	(1) (2) (3)	0.480 0.344 0.345	0.480 0.344 0.345
31	PKMI (LOCO)	3F5.3	(1) (2) (3)	0.385 0.296 0.398	0.385 0.296 0.398
32	PKMI (PACKBOARD)	3F5.3	(1) (2) (3)	0.540 0.406 0.478	0.540 0.406 0.478
33	PKPROD (ALICE LC-2)	3F7.4	(1) (2) (3)	-0.0014 -0.0948 -0.0243	-0.0014 -0.0948 -0.0243
34	PKPROD (ALICE LC-1)	3F7.4	(1) (2) (3)	0.0077 -0.0812 -0.0046	0.0077 -0.0812 -0.0046
35	PKPROD (LOCO)	3F7.4	(1) (2) (3)	0.0085 0.2408 0.1368	0.0085 0.2408 0.1368
36	PKPROD (PACKBOARD)	3F7.4	(1) (2) (3)	-0.0043 0.0558 0.0790	-0.0043 0.0558 0.0790
37	PKDIM (ALICE LC-2)	3F5.3	(1) (2) (3)	0.400 0.460 0.510	0.400 0.460 0.510
38	PKDIM (ALICE LC-1)	3F5.3	(1) (2) (3)	0.390 0.460 0.510	0.390 0.460 0.510

Card No.	Variable name	Format	Values		Male	Female
39	PKDIM (LOCO)	3F5.3	(1)		0.280	0.280
			(2)		0.370	0.370
			(3)		0.630	0.630
40	PKDIM (PACKBOARD)	3F5.3	(1)		0.290	0.290
			(2)		0.460	0.460
			(3)		0.550	0.550
41	PKPROP (ALICE LC-2)	3F4.2	(1)		0.49	0.49
			(2)		0.50	0.50
			(3)		0.51	0.51
42	PKPROP (ALICE LC-1)	3F4.2	(1)		0.50	0.50
			(2)		0.50	0.50
			(3)		0.52	0.52
43	PKPROP (LOCO)	3F4.2	(1)		0.38	0.38
			(2)		0.50	0.50
			(3)		0.67	0.67
44	PKPROP (PACKBOARD)	3F4.2	(1)		0.47	0.47
			(2)		0.50	0.50
			(3)		0.49	0.49
45	SMASS (added Loads)	2F5.2	Set by user			
46	LDPROP (added Load 1)	3F4.2	Set by user			
47	LDPROP (added Load 2)	3F4.2	Set by user			
48	STAT, XMASS	2F6.3	(1)		1.744	1.628
			(2)		72.655	61.208
49	RIFPT1	3F6.3	(1)		0.384	0.347
			(2)		−0.226	−0.210
			(3)		1.067	0.998
50	RIFPT2	3F6.3	(1)		0.384	0.347
			(2)		0.506	0.552
			(3)		1.067	0.998
51	RIFPT3	3F6.3	(1)		0.384	0.347
			(2)		−0.044	−0.028
			(3)		0.949	0.880

```
C
C              THE BIOMECHANICS OF LOAD CARRYING BEHAVIOR:
C              SYSTEM INERTIAL CHARACTERISTICS--3D PROGRAM.
C
C     COMPUTER LANGUAGE:   FORTRAN WATFOR
C
C     THIS PROGRAM WAS ORIGINALLY WRITTEN BY RICHARD N. HINRICHS
C     FOR JIS MASTERS THESIS ENTITLED "PRINCIPAL AXES AND
C     MOMENTS OF INERTIA OF THE HUMAN BODY: AN INVESTIGATION
C     OF THE STABILITY OF ROTARY MOTIONS" (UNIVERSITY OF IOWA,
C     1978).   IT WAS ADAPTED FOR USE IN THIS PROJECT BY PHILIP
C     E. MARTIN AND RICHARD N. HINRICHS OF THE PENNSYLVANIA
C     STATE UNIVERSITY BIOMECHANICS LABORATORY.
C
C     THIS PROGRAM READS XYZ COORDINATES OF SEVERAL BODY AND
C     EQUIPMENT LANDMARKS AND COMPUTES THE FOLLOWING:
C        A.   XYZ COORDINATES OF THE WHOLE SYTEM CG
C        B.   THE 3 CENTRAL MOMENTS AND 3 CENTRAL PRODUCTS OF INERTIA
C             IN XYZ OF THE WHOLE SYSTEM
C        C.   THE 3 CENTRAL PRINCIPAL MOMENTS OF INERTIA OF THE
C             WHOLE SYSTEM
C        D.   THE ORIENTATIONS OF THE 3 CENTRAL PRINCIPAL AXES
C
C     THE MODEL IS COMPOSED OF 12 SEGMENTS, NUMBERED AS FOLLOWS
C     (THE INFORMATION IN PARENTHESES INDICATES HOW THE SEGMENT
C     WAS MODELED, IE. AS A RIGID BODY OR A POINT MASS):
C               1.  WHOLE BODY PLUS CLOTHING (RIGID)
C               2.  HELMET (POINT)
C               3.  FGHT GEAR 1--SHOVEL (POINT)
C               4.  FGHT GEAR 2--AMMO PACK (POINT)
C               5.  FGHT GEAR 3--AMMO PACK (POINT)
C               6.  FGHT GEAR 4--CANTEEN (POINT)
C               7.  LEFT BOOT (POINT)
C               8.  RIGHT BOOT (POINT)
C               9.  RIFLE (RIGID)
C              10.  PACK,FRAME, AND BASIC 20# LOAD (RIGID)
C              11.  ADDED LOAD 1 (POINT)
C              12.  ADDED LOAD 2 (POINT)
C
C     BOTH MALE AND FEMALE MODELS WERE DEVELOPED FOR THIS PROJECT.
C     THESE WERE CONSTRUCTED USING THE ANTHROPOMETRIC DATA PROVIDED
C     BY THE 1966 AND 1977 ARMY ANTHROPOMETRIC REPORTS.   IN BOTH
C     CASES, THE 50TH PERCENTILE DATA WERE USED IN CONJUNCTION
C     WITH THE RESULTS OF HANAVAN AND CLAUSER ET AL.
C
C     THE FOLLOWING DEFINES THE MAJOR VARIABLES USED IN THIS PROGRAM:
C       CF:           CORRECTION FACTORS USED IN LOCATING PACKS RELATIVE
C                         TO THE SHOULDER.
C       COO:          XYZ COORDINATES OF THE SEGMENTAL CG'S.
C       HEAD:         HEADER INFORMATION DESCRIBING RUN.
C       LDPROP:       DESIRED LOCATION OF THE ADDED LOADS REPRESENTED
C                         AS A PERCENTAGE OF THE PACK DIMENSIONS.
C       NCOND:        NUMBER OF DIFFERENT CONDITIONS TO BE EXAMINED
C                         IN ONE RUN.
C       NPACK:        PACK TO BE USED--THEY ARE NUMBERED AS FOLLOWS:
C                         1.ALICE LC-2  2.ALICE LC-1  3.LOCO  4.PACKBOARD
C       NSEX:         SEX OF THE MODEL HUMAN: 1.MALE  2.FEMALE
C       PISCG:        INERTIA TENSOR OF EACH SEGMENT RELATIVE TO LOCAL
```

```
C                           AXES.
C        PKDIM:      DIMENSIONS OF THE PACKS.
C        PKMASS:     MASS OF THE PACKS.
C        PKMI:       MOMENTS OF INERTIA OF THE PACKS.
C        PKPROD:     PRODUCTS OF INERTIA OF THE PACKS.
C        PKPROP:     CG LOCATION OF EACH PACK REPRESENTED AS A PER-
C                    CENTAGE OF THE PACK DIMENSIONS.
C        PRODIN:     SEGMENTAL PRODUCTS OF INERTIA: 1.XY  2.XZ  3.YZ
C        RIFPT*:     THREE POINTS ON THE RIFLE USED TO DEFINE ITS
C                    LOCATION IN SPACE.
C        SEGMID:     SEGMENTAL MOMENT OF INERTIA ABOUT ITS DORSO-
C                    VENTRAL AXIS.
C        SEGMIL:     SEGMENTAL MOMENT OF INERTIA ABOUT ITS LONG-
C                    ITUDINAL AXIS.
C        SEGMIT:     SEGMENTAL MOMENT OF INERTIA ABOUT ITS TRANS-
C                    VERSE AXIS.
C        SHOUL:      XYZ COORDINATES OF THE LEFT AND RIGHT SHOULDERS.
C        SMASS:      SEGMENTAL MASSES.
C        STAT:       BODY HEIGHT.
C        SYSMS:      TOTAL SYSTEM MASS (NOT BODY MASS).
C        TISBCG:     INERTIA TENSOR OF EACH SEGMENT RELATIVE TO THE
C                    SYSTEM CG.
C        WBCPMI:     SYSTEM PRINCIPAL MOMENTS OF INERTIA.
C        WBICGR:     WHOLE SYSTEM INERTIA TENSOR THROUGH SYSTEM CG.
C        XMASS:      MASS OF THE BODY PLUS CLOTHING (NOT SYSTEM MS).
C        XXCG:       XYZ COORDINATES OF THE SYSTEM CG.
C
C    THE FOLLOWING DESCRIBES THE UNITS USED ON THE VARIOUS
C    TYPES OF VARIABLES USED IN THIS PROJECT.  THESE UNITS
C    APPLY TO BOTH INPUT AND OUTPUT DATA.
C       DISTANCES: METERS
C       MASSES: KILOGRAMS
C       MOMENTS OF INERTIA: KILOGRAM*METERS**2
C       PRODUCTS OF INERTIA: KILOGRAM*METERS**2
C       PRINCIPAL AXES: DENOTED BY DIRECTION COSINES
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        COMMON /INER/ SEGMIL(12),SEGMIT(12),SEGMID(12),SMASS(12),
     &                PRODIN(12,3)
        COMMON /COOR/ COO(2,12,3),SHOUL(2,3),RIFPT1(3),RIFPT2(3),
     &                RIFPT3(3)
        COMMON /CORRF/ CF(4,3)
        COMMON /PK/ PKMI(4,3),PKMASS(4),PKDIM(4,3),PKPROP(4,3),
     &                PKPROD(4,3)
        DIMENSION XXCG(3),USL(3),UST(3),USD(3),PISCG(12,3,3),XLAMDA(3,3),
     &            A(3),TISBCG(12,3,3),WBICGR(3,3),WBCPMI(3),WBCPAX(3,3),
     &            XLAMDT(3,3),PISCG1(3,3),RISCG1(3,3),ZZ(3,3),OP(3)
        DOUBLE PRECISION XBICGR(6),EIGNVL(3),EIGNVR(3,3),WK(10)
        LOGICAL*1 READ(50)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    READ NUMBER OF CONDITIONS TO BE EXAMINED IN THIS RUN
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        READ(5,10) NCOND
 10     FORMAT(I2)
C
        DO 999 NC=1,NCOND
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
```

```
C     READ HEADER INFORMATION AND THE SEX AND PACK TO BE USED
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,20)  HEAD,NSEX,NPACK
  20  FORMAT(50A1,/,2I1)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     MASS, MOMENT AND PRODUCT OF INERTIA VALUES, AND CG LOCATIONS ARE
C     READ IN FOR THE NINE SEGMENTS EXCLUDING PACK AND ADDED LOADS
C
C     J INDICATES SEGMENT NUMBER
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,30)  (SMASS(J),J=1,9)
  30  FORMAT(9F6.3)
      READ(5,40)  (SEGMIL(J),J=1,9),(SEGMIT(J),J=1,9),(SEGMID(J),J=1,9)
  40  FORMAT(9F7.4,2(/,9F7.4))
      DO 50 J=1,9
      READ(5,60)  (PRODIN(J,K),K=1,3)
  60  FORMAT(3F7.4)
  50  CONTINUE
      DO 70 J=1,9
      READ(5,80)  (COO(NSEX,J,K),K=1,3)
  80  FORMAT(3F6.3)
  70  CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     READ IN COORDINATES FOR THE SHOULDERS
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,90)  ((SHOUL(J,K),K=1,3),J=1,2)
  90  FORMAT(6F6.3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     READ IN CORRECTION FACTORS USED IN LOCATING PACKS AND ADDED
C     LOADS RELATIVE TO THE SHOULDERS
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,100)  ((CF(I,J),J=1,3),I=1,4)
 100  FORMAT(12F6.3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     CALL SUBROUTINES PKDAT AND LDDAT TO READ IN DATA FOR THE PACKS
C     AND ADDED LOADS AND TO CALCULATE LOCATIONS FOR THEM
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      CALL  PKDAT(NPACK,NSEX)
      CALL  LDDAT(NPACK,NSEX)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     THE STANDING HEIGHT (STAT) IN METERS AND THE MASS OF THE BODY
C     (XMASS) IN KG ARE READ IN
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,110)  STAT,XMASS
 110  FORMAT(2F6.3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     CORRECTION OF THE BODY MOMENTS OF INERTIA:
C     THE MOMENT OF INERTIA VALUES USED ARE FOR AN INDIVIDUAL OF 73.4
```

```
C    KG MASS AND 1.755 METERS HEIGHT.  THESE VALUES SHOULD BE COORECTED
C    FOR THE MODEL BEING ANALYZED.  CORRFA IS THE COORECTION FACTOR FOR
C    THE TRANSVERSE AND DORSOVENTRAL MOMENTS.  CORRFB IS THE CORRECTION
C    FACTOR FOR THE LONGITUDINAL MOMENT.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        CORRFA=XMASS*(STAT**2)/74.2/(1.755**2)
        CORRFB=(XMASS**2)*1.755/(74.2**2)/STAT
        SEGMIL(1)=SEGMIL(1)*CORRFB
        SEGMIT(1)=SEGMIT(1)*CORRFA
        SEGMID(1)=SEGMID(1)*CORRFA
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    THE LOCATION OF THE WHOLE SYSTEM CENTER OF GRAVITY (XXCG) IS
C    DETERMINED
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        DO 120 I=1,3
        XXCG(I)=0.
 120    CONTINUE
        SYSMS=0.
        DO 130 J=1,12
        SYSMS=SYSMS+SMASS(J)
 130    CONTINUE
        DO 140 K=1,3
        X=0.
        DO 150 J=1,12
        X=X+SMASS(J)*COO(NSEX,J,K)
 150    CONTINUE
        XXCG(K)=X/SYSMS
 140    CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    READ IN THREE RIFLE COORDINATES WHICH DEFINE POSITION OF THE
C    RIFLE RELATIVE TO THE BODY AND WHICH WILL BE USED TO DEFINE
C    UNIT VECTORS ALONG THE THREE AXES OF THE RIFLE.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        READ(5,160)  (RIFPT1(I),I=1,3),(RIFPT2(I),I=1,3),(RIFPT3(I),I=1,3)
 160    FORMAT(3F6.3,2(/,3F6.3))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    CALL SUBROUTINE AXLOC TO DEFINE UNIT VECTORS (USL,UST,USD).  THESE
C    AXES WERE ESTABLISHED DURING OSCILLATION TESTING.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        CALL AXLOC(RIFPT1,RIFPT2,RIFPT3,USL,UST,USD,OP)
        DO 170 I=1,3
        UST(I)=-UST(I)
        USD(I)=-USD(I)
 170    CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    THE INERTIA TENSOR (PISCG) IS ESTABLISHED FOR ALL SEGMENTS
C    RELATIVE TO THE LOCAL AXES OF EACH SEGMENT
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
        DO 180 J=1,12
        PISCG(J,1,1)=SEGMID(J)
        PISCG(J,1,2)=PRODIN(J,1)
```

```
              PISCG (J,1,3)=PRODIN(J,2)
              PISCG (J,2,1)=PRODIN(J,1)
              PISCG (J,2,2)=SEGMIT(J)
              PISCG (J,2,3)=PRODIN(J,3)
              PISCG (J,3,1)=PRODIN(J,2)
              PISCG (J,3,2)=PRODIN(J,3)
              PISCG (J,3,3)=SEGMIL(J)
      180     CONTINUE
CCCCCCCCCCCCCCCLCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    THE RIFLE INERTIA TENSOR MUST BE RELATED TO THE XYZ COORDINATE
C    SYSTEM.  XLAMDA, THE TRANSFORMATION MATRIX BETWEEN THE FIXED
C    XYZ REFERENCE SYSTEM AND THE RIFLE REFERENCE SYSTEM, AND
C    XLAMDT, ITS TRANSPOSE, ARE DEFINED
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
              DO 190 K=1,3
              XLAMDA (K,1)=USD(K)
              XLAMDA (K,2)=UST(K)
              XLAMDA (K,3)=USL(K)
      190     CONTINUE
              CALL TRANSP(XLAMDA,XLAMDT)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    THE RIFLE INERTIA TENSOR (PISCG) IS ROTATED INTO THE FIXED XYZ
C    REFERENCE FRAME
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
              DO 200 K=1,3
              DO 210 L=1,3
      210     PISCG1(K,L)=PISCG(9,K,L)
      200     CONTINUE
              CALL MATRXM(XLAMDA,PISCG1,ZZ,3,3,3)
              CALL MATRXM(ZZ,XLAMDT,RISCG1,3,3,3)
              DO 220 K=1,3
              DO 230 L=1,3
      230     PISCG(9,K,L)=RISCG1(K,L)
      220     CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    THE SEGMENT INERTIA TENSOR (PISCG) IS TRANSFERED VIA THE PARALLEL
C    AXIS THEOREM TO THE SYSTEM CG.  TISBCG IS THE SEGMENT INERTIA
C    TENSOR RELATIVE TO THE SYSTEM CG IN XYZ
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
              DO 240 J=1,12
              DO 250 K=1,3
              A(K)=XXCG(K)-COO(NSEX,J,K)
      250     CONTINUE
              TISBCG(J,1,1)=PISCG(J,1,1)+SMASS(J)*(A(2)**2+A(3)**2)
              TISBCG(J,1,2)=PISCG(J,1,2)-SMASS(J)*A(1)*A(2)
              TISBCG(J,1,3)=PISCG(J,1,3)-SMASS(J)*A(1)*A(3)
              TISBCG(J,2,1)=TISBCG(J,1,2)
              TISBCG(J,2,2)=PISCG(J,2,2)+SMASS(J)*(A(1)**2+A(3)**2)
              TISBCG(J,2,3)=PISCG(J,2,3)-SMASS(J)*A(2)*A(3)
              TISBCG(J,3,1)=TISBCG(J,1,3)
              TISBCG(J,3,2)=TISBCG(J,2,3)
              TISBCG(J,3,3)=PISCG(J,3,3)+SMASS(J)*(A(1)**2+A(2)**2)
      240     CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
```

```
C
C     THE CONTRIBUTION OF EACH SEGMENT IS ADDED UP.   WBICGR IS THE
C     SYSTEM INERTIA TENSOR THROUGH ITS CG IN XYZ
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
          DO 260 K=1,3
          DO 270 L=1,3
  270     WBICGR(K,L)=0.
  260     CONTINUE
          DO 280 J=1,12
          DO 290 K=1,3
          DO 300 L=1,3
  300     WBICGR(K,L)=WBICGR(K,L)+TISBCG(J,K,L)
  290     CONTINUE
  280     CONTINUE
          XBICGR(1)=WBICGR(1,1)
          XBICGR(2)=WBICGR(2,1)
          XBICGR(3)=WBICGR(2,2)
          XBICGR(4)=WBICGR(3,1)
          XBICGR(5)=WBICGR(3,2)
          XBICGR(6)=WBICGR(3,3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     THE SYSTEM INERTIA TENSOR WBICGR IS DIAGONALIZED TO DETERMINE
C     THE SYSTEM PRINCIPAL MOMENTS OF INERTIA AND THE CORRESPONDING
C     PRINCIPAL AXES DIRECTIONS.  THE IMSL SUBROUTINE EIGRS DETERMINES
C     THE EIGENVALUES AND THE EIGENVECTORS OF A REAL SYMMETRIC MATRIX.
C     THE EIGENVALUES ARE THE SYSTEM CENTRAL PRINCIPAL MOMENTS OF
C     INERTIA (WBCPMI). THE EIGENVECTORS ARE THE UNIT VECTORS IN THE
C     PRINCIPAL AXES DIRECTIONS (WBCPAX).
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
          CALL EIGRS(XBICGR,3,2,EIGNVL,EIGNVR,3,WK,IER)
          DO 330 K=1,3
          DO 340 L=1,3
          WBCPAX(K,L)=EIGNVE(K,L)
  340     CONTINUE
          WBCPMI(K)=EIGNVL(K)
  330     CONTINUE
          PERPI=WK(1)
          IERROR=IER
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C     PRINT THE RESULTS OF THE ANALYSIS
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
          WRITE(6,601)
  601     FORMAT('1',131('_'))
          WRITE(6,600) HEAD,NSEX,XMASS,STAT,SYSMS,NPACK,SMASS(11),
         &               SMASS(12)
  600     FORMAT('-',T30,'SYSTEM INERTIAL CHARACTERISTICS FOR A HUMAN',
         &     '-PACK MODEL',////,1X,50A1,//,5X,'SEX:',
         &     2X,I1,10X,'(NOTE: 1=MALE  2=FEMALE)',/,
         &     5X,'BODY MASS (KG):',2X,F6.2,/,5X,'BODY HEIGHT (M):',2X,
         &     F5.3,/,5X,'SYSTEM MASS (KG):',2X,F6.2,/,5X,'PACK:',2X,I1,
         &     10X,'(NOTE: 1=ALICE LC-2, 2=ALICE LC-1, 3=LOCO, 4=PACKBOARD)',/,
         &     5X,'ADDED LOAD #1 MASS (KG):',2X,F5.2,/,5X,
         &     'ADDED LOAD #2 MASS (KG):',2X,F5.2)
          WRITE(6,610)
  610     FORMAT('-',16X,'SEGMENT',9X,'CM COORDINATES',10X,
```

```
     &     'MOMENTS OF INERTIA',12X,'PRODUCTS OF INERTIA',/,
     &     5X,'SEGMENT',6X,'MASS',9X,'X',7X,'Y',7X,'Z',7X,'XX',
     &     8X,'YY',8X,'ZZ',8X,'XY',8X,'XZ',8X,'YZ')
      WRITE(6,620)
 620  FORMAT('+',4X,105('_'),/)
      DO 615 J=1,12
      WRITE(6,630) J,SMASS(J),(COO(NSEX,J,K),K=1,3),SEGMID(J),
     &     SEGMIT(J),SEGMIL(J),(PRODIN(J,K),K=1,3)
 630  FORMAT(8X,I2,6X,F6.3,6X,2(F6.3,2X),F6.3,6(3X,F7.4))
 615  CONTINUE
C
      WRITE(6,640) (XXCG(I),I=1,3)
 640  FORMAT('0',4X,'TOTAL SYSTEM CM LOCATION--  X:',F6.3,2X,
     &     'Y:',F6.3,2X,'Z:',F6.3)
      WRITE(6,650)
 650  FORMAT('-','INERTIA TENSOR: MOMENTS AND PRODUCTS OF INERTIA',
     &     //,4X,'IXX',7X,'IYY',7X,'IZZ',7X,'IXY',7X,'IXZ',7X,'IYZ',/)
      WRITE(6,660) (WBICGR(K,K),K=1,3),WBICGR(1,2),WBICGR(1,3),
     &     WBICGR(2,3)
 660  FORMAT(1X,6(F7.3,3X))
      WRITE(6,670)
 670  FORMAT('1',4('-'),'PRINCIPAL MOMENTS',3('-'),4X,34('-'),
     &     'PRINCIPAL AXES',33('-'))
      WRITE(6,680)
 680  FORMAT('0', 3X,'I11',5X,'I22',5X,'I33',8X,'1X',7X,'1Y',
     &     7X,'1Z',8X,'2X',7X,'2Y',7X,'2Z',8X,'3X',7X,'3Y',7X,'3Z',
     &     7X,'PERFI',2X,'ERR')
      WRITE(6,690)
 690  FORMAT('0',8('-'),'KG*M**2',9('-'),/)
      WRITE(6,700) (WBCPMI(K),K=1,3),((WBCPAX(K,L),K=1,3),L=1,3),
     &     PERFI,IERROR
 700  FORMAT(' ',3(F7.3,1X),2X,3(3F9.5,1X),1X,F7.3,2X,I3,//)
      WRITE(6,602)
 602  FORMAT(' ',130('_'))
C
 999  CONTINUE
      STOP
      END
      SUBROUTINE MATRXM(A,B,C,L,M,N)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE MATRXM PERFORMS MATRIX MULTIPLICATION BETWEEN A MATRIX
C    A(L,M) AND B(M,N), PRODUCING A MATRIX C(L,N).
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION A(L,M),B(M,N),C(L,N),R(3)
      DO 40 I=1,L
      DO 20 J=1,N
      R(J)=0
      DO 10 K=1,M
 10   R(J)=A(I,K)*B(K,J)+R(J)
 20   CONTINUE
      DO 30 J=1,N
 30   C(I,J)=R(J)
 40   CONTINUE
      RETURN
      END
      FUNCTION VMAG (V)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
```

```
C     FUNCTION VMAG READS A VECTOR V AND COMPUTES ITS MAGNITUDE.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION V(3)
      VMAG=SQRT(V(1)**2+V(2)**2+V(3)**2)
      RETURN
      END
      SUBROUTINE UNIVEC(V,UV)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE UNIVEC READS A VECTOR V AND COMPUTES THE UNIT VECTOR UV
C    ALONG THE SAME DIRECTION AS V.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION V(3),UV(3)
      P1=VMAG(V)
      IF(P1.EQ.0.) GO TO 20
      DO 10 K=1,3
      UV(K)=V(K)/P1
   10 CONTINUE
      GO TO 40
   20 DO 30 K=1,3
      UV(K)=0.
   30 CONTINUE
   40 RETURN
      END
      SUBROUTINE VECTP(V1,V2,V3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE VECTP COMPUTES THE VECTOR (CROSS) PRODUCT (V3) OF TWO
C    VECTORS (V1 AND V2).
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION V1(3),V2(3),V3(3)
      V3(1)=(V1(2)*V2(3))-(V1(3)*V2(2))
      V3(2)=(V1(3)*V2(1))-(V1(1)*V2(3))
      V3(3)=(V1(1)*V2(2))-(V1(2)*V2(1))
      RETURN
      END
      SUBROUTINE TRANSP(A,AT)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE TRANSP TAKES A 3 BY 3 MATRIX (A) AND DETERMINES ITS
C    TRANSPOSE (AT).
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION A(3,3),AT(3,3)
      DO 20 I=1,3
      DO 10 J=1,3
   10 AT(I,J)=A(J,I)
   20 CONTINUE
      RETURN
      END
      SUBROUTINE PKDAT (NPACK,NSEX)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    SUBROUTINE PKDAT READS IN VARIOUS DATA FOR THE 4 PACKS
C    AND CALCULATES CG LOCATION RELATIVE TO THE EXTENAL XYZ
C    COORDINATE SYSTEM.
C
```

```
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      COMMON /PK/ PKMI(4,3),PKMASS(4),PKDIM(4,3),PKPROP(4,3),
     &           PKPROD(4,3)
      COMMON /INER/ SEGMIL(12),SEGMIT(12),SEGMID(12),SMASS(12),
     &              PRODIN(12,3)
      COMMON /CORRF/ CF(4,3)
      COMMON /COOR/ COO(2,12,3),SHOUL(2,3),RIFPT1(3),RIFPT2(3),RIFPT3(3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   READ IN PACK MASSES, MOMENTS AND PRODUCTS OF INERTIA, MAXIMUM
C   DIMENSIONS IN THREE DIRECTIONS, PACK LOCATION RELATIVE TO SHOUL-
C   DER (CORR FACTOR), AND CG LOCATIONS REPRESENTED AS A PERCENTAGE
C   OF THESE DIMENSIONS.  THESE PERCENTAGES ARE REPRESENTED
C   IN THE FOLLOWING WAY: X-DIR-DISTANCE IS MEASURED FROM
C   FROM THE FRONT OF THE PACK (NEAREST THE BODY),Y-DIR-
C   DISTANCE IS FROM LEFT PACK EDGE, Z-DIR: DISTANCE IS FROM
C   TOP OF THE PACK.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,100) (PKMASS(I),I=1,4)
  100 FORMAT (4F5.2)
      READ(5,110) ((PKMI(I,J),J=1,3),I=1,4)
  110 FORMAT (3F5.3,3(/,3F5.3))
      READ(5,120) ((PKPROD(I,J),J=1,3),I=1,4)
  120 FORMAT(3F7.4,3(/,3F7.4))
      READ(5,110) ((PKDIM(I,J),J=1,3),I=1,4)
      READ(5,130) ((PKPROP(I,J),J=1,3),I=1,4)
  130 FORMAT (3F4.2,3(/,3F4.2))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   CALCULATE CG LOCATION OF SPECIFIED PACK RELATIVE TO THE
C   EXTERNAL XYZ COORDINATE SYSTEM.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      COO(NSEX,10,1) = -CF(NPACK,1)-(PKPROP(NPACK,1) * PKDIM(NPACK,1))
      COO(NSEX,10,2) = (PKDIM(NPACK,2)/2.)-(PKDIM(NPACK,2) *
     &   PKPROP(NPACK,2))
      COO(NSEX,10,3) = SHOUL(1,3)+CF(NPACK,3)-(PKDIM(NPACK,3) *
     &   PKPROP(NPACK,3))
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   ASSIGN VALUES FOR MASS AND MOMENT OF INERTIA FOR SELECTED
C   PACK TO ARRAYS SMASS, SEGMIL, ETC. AND RETURN
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      SMASS(10) = PKMASS(NPACK)
      SEGMIL(10) = PKMI(NPACK,1)
      SEGMIT(10) = PKMI(NPACK,2)
      SEGMID(10) = PKMI(NPACK,3)
      DO 140 I=1,3
      PRODIN(10,I)=PKPROD(NPACK,I)
  140 CONTINUE
      RETURN
      END
      SUBROUTINE LDDAT (NPACK,NSEX)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   SUBROUTINE LDDAT READS IN VALUES FOR THE MAGNITUDE OF THE
C   EXTRA LOADS AND CALCULATES THE LOCATION OF THE EXTRA LOADS
C   RELATIVE TO THE EXTERNAL XYZ COORDINATE SYSTEM.
```

```
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      COMMON /PK/ PKMI(4,3),PKMASS(4),PKDIM(4,3),PKPROP(4,3),
     &            PKPROD(4,3)
      COMMON /INER/ SEGMIL(12),SEGMIT(12),SEGMID(12),SMASS(12),
     &            PRODIN(12,3)
      COMMON /CORRF/ CF(4,3)
      COMMON /COOR/ COO(2,12,3),SHOUL(2,3),RIPPT1(3),RIPPT2(3),RIPPT3(3)
      REAL LDPROP(2,3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   READ IN MAGNITUDES OF DESIRED EXTRA LOADS AND LOCATION
C   AS A PROPORTION OF PACK DIMENSIONS.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      READ(5,100)  (SMASS(I),I=11,12)
 100  FORMAT(2F5.2)
      READ(5,110)  ((LDPROP(I,J),J=1,3),I=1,2)
 110  FORMAT(3F4.2,/,3F4.2)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   INITIALIZE VARIABLES
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DO 115 I=11,12
      DO 115 J=1,3
      COO(NSEX,I,J)=0.
 115  CONTINUE
      SEGMIL(11) = 0.
      SEGMIT(11) = 0.
      SEGMID(11) = 0.
      SEGMIL(12) = 0.
      SEGMIT(12) = 0.
      SEGMID(12) = 0.
      DO 120 I=1,3
      PRODIN(11,I)=0.
      PRODIN(12,I)=0.
 120  CONTINUE
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   CALCULATE LOCATION OF EXTRA LOADS RELATIVE TO THE EXTERNAL
C   XYZ COORDINATE SYSTEM AND THEN RETURN.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      IF(SMASS(11).EQ.0) GO TO 130
      COO(NSEX,11,1) = -CF(NPACK,1)-(LDPROP(1,1)*PKDIM(NPACK,1))
      COO(NSEX,11,2) = (PKDIM(NPACK,2)/2.)-(PKDIM(NPACK,2) *
     &    LDPROP(1,2))
      COO(NSEX,11,3) = SHOUL(1,3)+CF(NPACK,3)-(PKDIM(NPACK,3) *
     &    LDPROP(1,3))
 130  CONTINUE
      IF(SMASS(12).EQ.0) GO TO 140
      COO(NSEX,12,1) = -CF(NPACK,1)-(LDPROP(2,1)*PKDIM(NPACK,1))
      COO(NSEX,12,2) = (PKDIM(NPACK,2)/2.)-(PKDIM(NPACK,2) *
     &    LDPROP(2,2))
      COO(NSEX,12,3) = SHOUL(1,3)+CF(NPACK,3)-(PKDIM(NPACK,3) *
     &    LDPROP(2,3))
 140  CONTINUE
      RETURN
      END
```

67

```
      SUBROUTINE AXLOC(A,B,C,AI,AJ,AK,OP)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   SUBROUTINE TO LOCATE A UNIT VECTOR TRIAD IN A RIGID BODY GIVEN
C   THE COORDINATES OF THREE POINTS A,B & C WHICH ARE NON-COLINEAR
C
C       X AXIS WILL BE ALONG AB
C       Y AXIS WILL BE THROUGH C PERPENDICULAR TO AB
C       Z AXIS WILL BE ( I X J )
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION A(3),B(3),C(3),AI(3),AJ(3),AK(3),OP(3),TV(3)
     *           ,AB(3),AC(3)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   1.DEFINE VECTORS AB AND AC
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      CALL VCOMP(A,B,AB)
      CALL VCOMP(A,C,AC)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   2.FIND THE ANGLE BETWEEN AB AND AC
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      THETA=ANGLE(AB,AC)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   3.CALCULATE THE LENGTH OF VECTOR AO'
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      ACLEN=VMAG(AC)
      AOP=ACLEN*COS(THETA)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   4.ESTABLISH THE COORDS OF O'
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      ABLEN=VMAG(AB)
      FACT=AOP/ABLEN
      CALL INTPT(A,B,OP,FACT)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   5.CALCULATE THE UNIT VECTORS ALONG O'B & O'C
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      CALL UNIVEC(AB,AI)
      CALL VCOMP(OP,C,TV)
      CALL UNIVEC(TV,AJ)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   6.CALCULATE UNIT VECTOR K BY VECTOR PRODUCT
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      CALL VECTP(AI,AJ,AK)
      RETURN
      END
      SUBROUTINE INTPT(A,B,C,RAT)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
```

```
C   SUBROUTINE TO FIND THE COORDINATES OF POINT C, INTERMEDIATE
C   BETWEEN POINTS A AND B SUCH THAT THE RATIO AC:AB = RAT
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION A(3),B(3),C(3)
C
      C(1)=A(1)+ (B(1)-A(1))*RAT
      C(2)=A(2)+ (B(2)-A(2))*RAT
      C(3)=A(3)+ (B(3)-A(3))*RAT
C
      RETURN
      END
      SUBROUTINE VCOMP(A,B,V)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   SUBROUTINE TO FIND THE COMPONENTS OF THE VECTOR JOINING POINT A & B
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION A(3),B(3),V(3)
      V(1)=B(1)-A(1)
      V(2)=B(2)-A(2)
      V(3)=B(3)-A(3)
      RETURN
      END
      FUNCTION ANGLE(A,B)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   FUNCION TO FIND THE ANGLE BETWEEN TWO VECTORS A AND B.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION A(3),B(3),X(3)
      VA=VMAG(A)
      VB=VMAG(B)
      IF(VA.NE.0..AND.VB.NE.0.)GO TO 50
C
      WRITE(5,10)VA,VB
10    FORMAT(' ***ERROR*** IN FUNCTION ANGLE--DIVIDE BY ZERO'/
     *          ' VMAG(A)= ',F10.3,'    VMAG(B)= ',F10.3)
      ANGLE=0.
      RETURN
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   THERE ARE TWO WAYS TO CALCULATE THE ANGLE BETWEEN TWO VECTORS.
C   WHEN THE ANGLE IS CLOSE TO 0 OR 180 DEGREES, ARSIN IS MORE ACCURATE.
C   WHEN THE ANGLE IS CLOSE TO 90 DEGREES, ARCOS IS MORE ACCURATE.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
50    Y=SCALP(A,B)
      IF(Y.GT.0.5)GO TO 70
      ANGLE=ARCOS(Y/(VA*VB))
      RETURN
C
70    CALL VECTP(A,B,X)
      ANGLE=ARSIN(VMAG(X)/(VA*VB))
      RETURN
      END
      FUNCTION SCALP(D,E)
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C   FUNCTION SCALP COMPUTES THE SCALAR (DOT) PRODUCT OF
```

69

```
C    TWO VECTORS, D AND E.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
      DIMENSION D(3),E(3)
      SCALP=D(1)*E(1)+D(2)*E(2)+D(3)*E(3)
      RETURN
      END
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C
C    THE FOLLOWING ARE SOURCE LISTINGS OF SIX IMSL SUBROUTINES
C    REQUIRED IN THIS PROGRAM.  THESE WERE NOT WRITTEN BY THE
C    AUTHORS BUT ARE CANNED PROGRAMS AVAILABLE TO PENN STATE
C    COMPUTATION CENTER USERS.
C
CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C    IMSL ROUTINE NAME    - EIGRS
C
C-----------------------------------------------------------------
C
C    COMPUTER             - IBM/DOUBLE
C
C    LATEST REVISION      - JUNE 1, 1980
C
C    PURPOSE              - EIGENVALUES AND (OPTIONALLY) EIGENVECTORS OF
C                           A REAL SYMMETRIC MATRIX
C
C    USAGE                - CALL EIGRS (A,N,JOBN,D,Z,IZ,WK,IER)
C
C    ARGUMENTS    A       - INPUT REAL SYMMETRIC MATRIX OF ORDER N,
C                           WHOSE EIGENVALUES AND EIGENVECTORS
C                           ARE TO BE COMPUTED. INPUT A IS
C                           DESTROYED IF IJOB IS EQUAL TO 0 OR 1.
C                 N       - INPUT ORDER OF THE MATRIX A.
C                 JOBN    - INPUT OPTION PARAMETER.  IF JOBN.GE.10
C                           A IS ASSUMED TO BE IN FULL STORAGE MODE
C                           (IN THIS CASE, A MUST BE DIMENSIONED EXACTLY
C                           N BY N IN THE CALLING PROGRAM).
C                           IF JOBN.LT.10 THEN A IS ASSUMED TO BE IN
C                           SYMMETRIC STORAGE MODE.  DEFINE
C                           IJOB=MOD(JOBN,10).  THEN WHEN
C                              IJOB = 0, COMPUTE EIGENVALUES ONLY
C                              IJOB = 1, COMPUTE EIGENVALUES AND EIGEN-
C                                 VECTORS.
C                              IJOB = 2, COMPUTE EIGENVALUES, EIGENVECTORS
C                                 AND PERFORMANCE INDEX.
C                              IJOB = 3, COMPUTE PERFORMANCE INDEX ONLY.
C                           IF THE PERFORMANCE INDEX IS COMPUTED, IT IS
C                           RETURNED IN WK(1). THE ROUTINES HAVE
C                           PERFORMED (WELL, SATISFACTORILY, POORLY) IF
C                           WK(1) IS (LESS THAN 1, BETWEEN 1 AND 100,
C                           GREATER THAN 100).
C                 D       - OUTPUT VECTOR OF LENGTH N,
C                           CONTAINING THE EIGENVALUES OF A.
C                 Z       - OUTPUT N BY N MATRIX CONTAINING
C                           THE EIGENVECTORS OF A.
C                           THE EIGENVECTOR IN COLUMN J OF Z CORRES-
C                           PONDS TO THE EIGENVALUE D(J).
C                           IF IJOB = 0, Z IS NOT USED.
C                 IZ      - INPUT ROW DIMENSION OF MATRIX Z EXACTLY AS
C                           SPECIFIED IN THE DIMENSION STATEMENT IN THE
```

70

```
C                              CALLING PROGRAM.
C              WK         - WORK AREA, THE LENGTH OF WK DEPENDS
C                              ON THE VALUE OF IJOB, WHEN
C                              IJOB = 0, THE LENGTH OF WK IS AT LEAST N.
C                              IJOB = 1, THE LENGTH OF WK IS AT LEAST N.
C                              IJOB = 2, THE LENGTH OF WK IS AT LEAST
C                                  N(N+1)/2+N.
C                              IJOB = 3, THE LENGTH OF WK IS AT LEAST 1.
C              IER        - ERROR PARAMETER (OUTPUT)
C                              TERMINAL ERROR
C                              IER = 128+J, INDICATES THAT EQRT2S FAILED
C                                  TO CONVERGE ON EIGENVALUE J. EIGENVALUES
C                                  AND EIGENVECTORS 1,....,J-1 HAVE BEEN
C                                  COMPUTED CORRECTLY, BUT THE EIGENVALUES
C                                  ARE UNORDERED. THE PERFORMANCE INDEX
C                                  IS SET TO 1000.0
C                              WARNING ERROR (WITH FIX)
C                                IN THE FOLLOWING, IJOB = MOD(JOBN,10).
C                                IER = 66, INDICATES IJOB IS LESS THAN 0 OR
C                                  IJOB IS GREATER THAN 3. IJOB SET TO 1.
C                                IER = 67, INDICATES IJOB IS NOT EQUAL TO
C                                  ZERO, AND IZ IS LESS THAN THE ORDER OF
C                                  MATRIX A. IJOB IS SET TO ZERO.
C
C    PRECISION/HARDWARE   - SINGLE AND DOUBLE/H32
C                          - SINGLE/H36,H48,H60
C
C    REQD. IMSL ROUTINES  - EHOBKS,EHOUSS,EQRT2S,UERTST,UGETIO
C
C    NOTATION             - INFORMATION ON SPECIAL NOTATION AND
C                              CONVENTIONS IS AVAILABLE IN THE MANUAL
C                              INTRODUCTION OR THROUGH IMSL ROUTINE UHELP
C
C    COPYRIGHT            - 1980 BY IMSL, INC. ALL RIGHTS RESERVED.
C
C    WARRANTY             - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN
C                              APPLIED TO THIS CODE. NO OTHER WARRANTY,
C                              EXPRESSED OR IMPLIED, IS APPLICABLE.
C
C------------------------------------------------------------------------
C
      SUBROUTINE EIGRS  (A,N,JOBN,D,Z,IZ,WK,IER)
C                                  SPECIFICATIONS FOR ARGUMENTS
      INTEGER            N,JOBN,IZ,IER
      DOUBLE PRECISION   A(1),D(1),WK(1),Z(IZ,1)
C                                  SPECIFICATIONS FOR LOCAL VARIABLES
      INTEGER            IJOB,IR,JR,IJ,JI,NP1
      INTEGER            JER,NA,ND,IIZ,IBEG,IL,KK,LK,I,J,K,L
      DOUBLE PRECISION   ANORM,ASUM,PI,SUMZ,SUMR,AN,S,TEN,RDELP,ZERO,
     1                   ONE,THOUS
      DATA               RDELP/Z3410000000000000/
      DATA               ZERO,ONE/0.0D0,1.0D0/,TEN/10.0D0/,THOUS/1000.0
     +0/
C                                  INITIALIZE ERROR PARAMETERS
C                                  FIRST EXECUTABLE STATEMENT
      IER = 0
      JER = 0
      IF (JOBN.LT.10) GO TO 15
C                                  CONVERT TO SYMMETRIC STORAGE MODE
      K = 1
```

```
      JI = N-1
      IJ = 1
      DO 10 J=1,N
         DO 5 I=1,J
            A(K) = A(IJ)
            IJ = IJ+1
            K = K+1
    5    CONTINUE
         IJ = IJ + JI
         JI = JI - 1
   10 CONTINUE
   15 IJOB = MOD(JOBN,10)
      IF (IJOB.GE.0.AND.IJOB.LE.3) GO TO 20
C                                     WARNING ERROR - IJOB IS NOT IN THE
C                                     RANGE
      IER = 66
      IJOB = 1
      GO TO 25
   20 IF (IJOB.EQ.0) GO TO 35
   25 IF (IZ.GE.N) GO TO 30
C                                     WARNING ERROR - IZ IS LESS THAN N
C                                     EIGENVECTORS CAN NOT BE COMPUTED,
C                                     IJOB SET TO ZERO
      IER = 67
      IJOB = 0
   30 IF (IJOB.EQ.3) GO TO 75
   35 NA = (N*(N+1))/2
      IF (IJOB.NE.2) GO TO 45
      DO 40 I=1,NA
         WK(I) = A(I)
   40 CONTINUE
C                                     SAVE INPUT A IF IJOB = 2
   45 ND = 1
      IF (IJOB.EQ.2) ND = NA+1
C                                     REDUCE A TO SYMMETRIC TRIDIAGONAL
C                                     FORM
      CALL EHOUSS (A,N,D,WK(ND),WK(ND))
      IIZ = 1
      IF (IJOB.EQ.0) GO TO 60
      IIZ = IZ
C                                     SET Z TO THE IDENTITY MATRIX
      DO 55 I=1,N
         DO 50 J=1,N
            Z(I,J) = ZERO
   50    CONTINUE
         Z(I,I) = ONE
   55 CONTINUE
C                                     COMPUTE EIGENVALUES AND EIGENVECTORS
   60 CALL EQRT2S (D,WK(ND),N,Z,IIZ,JER)
      IF (IJOB.EQ.0) GO TO 9000
      IF (JER.GT.128) GO TO 65
C                                     BACK TRANSFORM EIGENVECTORS
      CALL EHOBKS (A,N,1,N,Z,IZ)
   65 IF (IJOB.LE.1) GO TO 9000
C                                     MOVE INPUT MATRIX BACK TO A
      DO 70 I=1,NA
         A(I) = WK(I)
   70 CONTINUE
      WK(1) = THOUS
      IF (JER.NE.0) GO TO 9000
```

```
C                                      COMPUTE 1 - NORM OF A
   75 ANORM = ZERO
      IBEG = 1
      DO 85 I=1,N
         ASUM = ZERO
         IL = IBEG
         KK = 1
         DO 80 L=1,N
            ASUM = ASUM+DABS(A(IL))
            IF (L.GE.I) KK = L
            IL = IL+KK
   80    CONTINUE
         ANORM = DMAX1(ANORM,ASUM)
         IBEG = IBEG+I
   85 CONTINUE
      IF (ANORM.EQ.ZERO) ANORM = ONE
C                                      COMPUTE PERFORMANCE INDEX
      PI = ZERO
      DO 100 I=1,N
         IBEG = 1
         S = ZERO
         SUMZ = ZERO
         DO 95 L=1,N
            LK = IBEG
            KK = 1
            SUMZ = SUMZ+DABS(Z(L,I))
            SUMR = -D(I)*Z(L,I)
            DO 90 K=1,N
               SUMR = SUMR+A(LK)*Z(K,I)
               IF (K.GE.L) KK = K
               LK = LK+KK
   90       CONTINUE
            S = S+DABS(SUMR)
            IBEG = IBEG+L
   95    CONTINUE
         IF (SUMZ.EQ.ZERO) GO TO 100
         PI = DMAX1(PI,S/SUMZ)
  100 CONTINUE
      AN = N
      PI = PI/(ANORM*TEN*AN*RDELP)
      WK(1) = PI
      IF (JOBN.LT.10) GO TO 9000
C                                      CONVERT BACK TO FULL STORAGE MODE
      NP1 = N+1
      IJ = (N-1)*NP1 + 2
      K = (N*(NP1))/2
      DO 110 JR=1,N
         J = NP1-JR
         DO 105 IB=1,J
            IJ = IJ-1
            A(IJ) = A(K)
            K = K-1
  105    CONTINUE
         IJ = IJ-JR
  110 CONTINUE
      JI = 0
      K = N-1
      DO 120 I=1,N
         IJ = I-N
         DO 115 J=1,I
```

73

```
            IJ = IJ+N
            JI = JI+1
            A(IJ) = A(JI)
  115     CONTINUE
          JI = JI + K
          K = K-1
  120 CONTINUE
 9000 CONTINUE
      IF (IER.NE.0) CALL UERTST (IER,6HEIGRS )
      IF (JER.EQ.0) GO TO 9005
      IER = JER
      CALL UERTST (IER,6HEIGRS )
 9005 RETURN
      END
C   IMSL ROUTINE NAME   - EHOBKS
C
C-----------------------------------------------------------------------
C
C   COMPUTER              - IBM/DOUBLE
C
C   LATEST REVISION       - JANUARY 1, 1978
C
C   PURPOSE               - BACK TRANSFORMATION TO FORM THE EIGENVECTORS
C                             OF THE ORIGINAL SYMMETRIC MATRIX FROM THE
C                             EIGENVECTORS OF THE TRIDIAGONAL MATRIX
C
C   USAGE                 - CALL EHOBKS (A,N,M1,M2,Z,IZ)
C
C   ARGUMENTS    A        - THE ARRAY CONTAINS THE DETAILS OF THE HOUSE-
C                             HOLDER REDUCTION OF THE ORIGINAL MATRIX A
C                             AS GENERATED BY IMSL ROUTINE EHOUSS.(INPUT)
C                N        - ORDER OF THE REAL SYMMETRIC MATRIX.(INPUT)
C                M1       - M1 AND M2 ARE TWO INPUT SCALARS SUCH THAT
C                             EIGENVECTORS M1 TO M2 OF THE TRIDIAGONAL
C                             MATRIX A HAVE BEEN FOUND AND NORMALIZED
C                             ACCORDING TO THE EUCLIDEAN NORM.
C                M2       - SEE ABOVE - M1
C                Z        - A TWO DIMENSIONAL ARRAY OF SIZE N X (M2-M1+1)
C                             WHICH CONTAINS EIGENVECTORS M1 TO M2 OF
C                             TRIDIAGONAL MATRIX T, NORMALIZED ACCORDING
C                             TO EUCLIDEAN NORM. INPUT Z CAN BE PRODUCED
C                             BY IMSL ROUTINE EQRT2S, THE RESULTANT
C                             MATRIX OVERWRITES THE INPUT Z.(INPUT/OUTPUT)
C                IZ       - ROW DIMENSION OF MATRIX Z EXACTLY AS
C                             SPECIFIED IN THE DIMENSION STATEMENT IN THE
C                             CALLING PROGRAM. (INPUT)
C
C   PRECISION/HARDWARE    - SINGLE AND DOUBLE/H32
C                         - SINGLE/H36,H48,H60
C
C   REQD. IMSL ROUTINES   - NONE REQUIRED
C
C   NOTATION              - INFORMATION ON SPECIAL NOTATION AND
C                             CONVENTIONS IS AVAILABLE IN THE MANUAL
C                             INTRODUCTION OR THROUGH IMSL ROUTINE UHELP
C
C   COPYRIGHT             - 1978 BY IMSL, INC. ALL RIGHTS RESERVED.
C
C   WARRANTY              - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN
C                             APPLIED TO THIS CODE. NO OTHER WARRANTY,
```

```
C                              EXPRESSED OR IMPLIED, IS APPLICABLE.
C
C-----------------------------------------------------------------------
C
      SUBROUTINE EHOBKS (A,N,M1,M2,Z,IZ)
C
      DIMENSION            A(1),Z(IZ,1)
      DOUBLE PRECISION     A,Z,H,S
C                                      FIRST EXECUTABLE STATEMENT
      IF (N .EQ. 1) GO TO 30
      DO 25 I=2,N
         L = I-1
         IA = (I*L)/2
         H = A(IA+I)
         IF (H.EQ.0.D0) GO TO 25
C                                      DERIVES EIGENVECTORS M1 TO M2 OF
C                                      THE ORIGINAL MATRIX FROM EIGENVECTORS
C                                      M1 TO M2 OF THE SYMMETRIC
C                                      TRIDIAGONAL MATRIX
         DO 20 J = M1,M2
            S = 0.0D0
            DO 10 K = 1,L
               S = S+A(IA+K)*Z(K,J)
   10       CONTINUE
            S = S/H
            DO 15 K=1,L
               Z(K,J) = Z(K,J)-S*A(IA+K)
   15       CONTINUE
   20    CONTINUE
   25 CONTINUE
   30 RETURN
      END
C    IMSL ROUTINE NAME   - EHOUSS
C
C-----------------------------------------------------------------------
C
C    COMPUTER             - IBM/DOUBLE
C
C    LATEST REVISION      - JANUARY 1, 1978
C
C    PURPOSE              - REDUCTION OF A SYMMETRIC MATRIX TO SYMMETRIC
C                           TRIDIAGONAL FORM USING A HOUSEHOLDER
C                           REDUCTION
C
C    USAGE                - CALL EHOUSS (A,N,D,E,E2)
C
C    ARGUMENTS    A       - THE GIVEN N X N, REAL SYMMETRIC MATRIX A,
C                           WHERE A IS STORED IN SYMMETRIC STORAGE MODE.
C                           THE INPUT A IS REPLACED BY THE DETAILS OF
C                           THE HOUSEHOLDER REDUCTION OF A.
C                 N       - INPUT ORDER OF A AND THE LENGTH OF D, E, AND
C                           E2.
C                 D       - THE OUTPUT ARRAY OF LENGTH N, GIVING THE
C                           DIAGONAL ELEMENTS OF THE TRIDIAGONAL MATRIX.
C                 E       - THE OUTPUT ARRAY OF LENGTH N, GIVING THE SUB-
C                           DIAGONAL IN THE LAST (N-1) ELEMENTS, E(1) IS
C                           SET TO ZERO.
C                 E2      - OUTPUT ARRAY OF LENGTH N.  E2(I) = E(I)**2.
C
C    PRECISION/HARDWARE   - SINGLE AND DOUBLE/H32
```

```
C                          - SINGLE/H36,H48,H60
C
C    REQD. IMSL ROUTINES - NONE REQUIRED
C
C    NOTATION               - INFORMATION ON SPECIAL NOTATION AND
C                               CONVENTIONS IS AVAILABLE IN THE MANUAL
C                               INTRODUCTION OR THROUGH IMSL ROUTINE UHELP
C
C    COPYRIGHT              - 1978 BY IMSL, INC. ALL RIGHTS RESERVED.
C
C    WARRANTY              - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN
C                               APPLIED TO THIS CODE. NO OTHER WARRANTY,
C                               EXPRESSED OR IMPLIED, IS APPLICABLE.
C
C--------------------------------------------------------------------------
C
      SUBROUTINE EHOUSS (A,N,D,E,E2)
C
      DIMENSION           A(1),D(N),E(N),E2(N)
      DOUBLE PRECISION    A,D,E,E2,ZERO,H,SCALE,ONE,SCALE1,F,G,HH
      DATA                ZERO/0.0D0/,ONE/1.0D0/
C                                    FIRST EXECUTABLE STATEMENT
      NP1 = N+1
      NN = (N*NP1)/2-1
      NBEG = NN+1-N
      DO 70 II = 1,N
         I = NP1-II
         L = I-1
         H = ZERO
         SCALE = ZERO
         IF (L .LT. 1) GO TO 10
C                                    SCALE ROW (ALGOL TOL THEN NOT NEEDED)
         NK = NN
         DO 5 K = 1,L
            SCALE = SCALE+DABS(A(NK))
            NK = NK-1
    5    CONTINUE
         IF (SCALE .NE. ZERO) GO TO 15
   10    E(I) = ZERO
         E2(I) = ZERO
         GO TO 65
   15    NK = NN
         SCALE1 = ONE/SCALE
         DO 20 K = 1,L
            A(NK) = A(NK)*SCALE1
            H = H+A(NK)*A(NK)
            NK = NK-1
   20    CONTINUE
         E2(I) = SCALE*SCALE*H
         F = A(NN)
         G = -DSIGN(DSQRT(H),F)
         E(I) = SCALE*G
         H = H-F*G
         A(NN) = F-G
         IF (L .EQ. 1) GO TO 55
         F = ZERO
         JK1 = 1
         DO 40 J = 1,L
            G = ZERO
            IK = NBEG+1
```

76

```
              JK = JK1                   FORM ELEMENT OF A*U
C
              DO 25 K = 1,J
                 G = G+A(JK)*A(IK)
                 JK = JK+1
                 IK = IK+1
   25         CONTINUE
              JP1 = J+1
              IF (L .LT. JP1) GO TO 35
              JK = JK+J-1
              DO 30 K = JP1,L
                 G = G+A(JK)*A(IK)
                 JK = JK+K
                 IK = IK+1
   30         CONTINUE                    FORM ELEMENT OF P
C
   35         E(J) = G/H
              F = F+E(J)*A(NBEG+J)
              JK1 = JK1+J
   40      CONTINUE
           HH = F/(H+H)                    FORM REDUCED A
C
           JK = 1
           DO 50 J = 1,L
              F = A(NBEG+J)
              G = E(J)-HH*F
              E(J) = G
              DO 45 K = 1,J
                 A(JK) = A(JK)-F*E(K)-G*A(NBEG+K)
                 JK = JK+1
   45         CONTINUE
   50      CONTINUE
   55      DO 60 K = 1,L
              A(NBEG+K) = SCALE*A(NBEG+K)
   60      CONTINUE
   65      D(I) = A(NBEG+I)
           A(NBEG+I) = H*SCALE*SCALE
           NBEG = NBEG-I+1
           NN = NN-I
   70   CONTINUE
        RETURN
        END
```

C   IMSL ROUTINE NAME   - EQRT2S
```
C
C
C-----------------------------------------------------------------------
C
C
C   COMPUTER          - IBM/DOUBLE
C
C   LATEST REVISION   - JANUARY 1, 1978
C
C   PURPOSE           - EIGENVALUES AND (OPTIONALLY) EIGENVECTORS OF
C                         A SYMMETRIC TRIDIAGONAL MATRIX USING THE
C                         QL METHOD.
C
C   USAGE             - CALL EQRT2S (D,E,N,Z,IZ,IER)
C
C   ARGUMENTS    D    - ON INPUT, THE VECTOR D OF LENGTH N CONTAINS
C                         THE DIAGONAL ELEMENTS OF THE SYMMETRIC
C                         TRIDIAGONAL MATRIX T.
C                       ON OUTPUT, D CONTAINS THE EIGENVALUES OF
C
```

```
C                                    T IN ASCENDING ORDER.
C                    E          - ON INPUT, THE VECTOR E OF LENGTH N CONTAINS
C                                    THE SUB-DIAGONAL ELEMENTS OF T IN POSITION
C                                    2,...,N. ON OUTPUT, E IS DESTROYED.
C                    N          - ORDER OF TRIDIAGONAL MATRIX T.(INPUT)
C                    Z          - ON INPUT, Z CONTAINS THE IDENTITY MATRIX OF
C                                    ORDER N.
C                                    ON OUTPUT, Z CONTAINS THE EIGENVECTORS
C                                    OF T. THE EIGENVECTOR IN COLUMN J OF Z
C                                    CORRESPONDS TO THE EIGENVALUE D(J).
C                    IZ         - INPUT ROW DIMENSION OF MATRIX Z EXACTLY AS
C                                    SPECIFIED IN THE DIMENSION STATEMENT IN THE
C                                    CALLING PROGRAM. IF IZ IS LESS THAN N, THE
C                                    EIGENVECTORS ARE NOT COMPUTED. IN THIS CASE
C                                    Z IS NOT USED.
C                    IER        - ERROR PARAMETER
C                                    TERMINAL ERROR
C                                    IER = 128+J, INDICATES THAT EQRT2S FAILED
C                                       TO CONVERGE ON EIGENVALUE J. EIGENVALUES
C                                       AND EIGENVECTORS 1,...,J-1 HAVE BEEN
C                                       COMPUTED CORRECTLY, BUT THE EIGENVALUES
C                                       ARE UNORDERED.
C
C      PRECISION/HARDWARE   - SINGLE AND DOUBLE/H32
C                            - SINGLE/H36,H48,H60
C
C      REQD. IMSL ROUTINES - UERTST,UGETIO
C
C      NOTATION             - INFORMATION ON SPECIAL NOTATION AND
C                              CONVENTIONS IS AVAILABLE IN THE MANUAL
C                              INTRODUCTION OR THROUGH IMSL ROUTINE UHELP
C
C      REMARKS       IMSL ROUTINE EQRT2S IS DESIGNED TO ACCEPT OUTPUT
C                    VECTORS D AND E FROM IMSL ROUTINE EHOUSS AS INPUT
C                    D AND E OF EQRT2S. GIVEN A SYMMETRIC TRIDIAGONAL
C                    MATRIX, T, VECTOR D CONTAINS THE DIAGONAL ELEMENTS
C                    OF T AND VECTOR E CONTAINS THE SUBDIAGONAL ELEMENTS
C                    OF T. SEE THE EHOUSS DOCUMENT.
C
C      COPYRIGHT            - 1978 BY IMSL, INC. ALL RIGHTS RESERVED.
C
C      WARRANTY             - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN
C                              APPLIED TO THIS CODE. NO OTHER WARRANTY,
C                              EXPRESSED OR IMPLIED, IS APPLICABLE.
C
C-----------------------------------------------------------------------
C
       SUBROUTINE EQRT2S (D,E,N,Z,IZ,IER)
C
       DIMENSION              D(1),E(1),Z(IZ,1)
       DOUBLE PRECISION       D,E,Z,B,C,F,G,H,P,R,S,RDELP,ONE,ZERO
       DATA                   RDELP/Z3410000000000000/
       DATA                   ZERO,ONE/0.0D0,1.0D0/
C                                       MOVE THE LAST N-1 ELEMENTS
C                                       OF E INTO THE FIRST N-1 LOCATIONS
C                                       FIRST EXECUTABLE STATEMENT
       IER  = 0
       IF (N .EQ. 1) GO TO 9005
       DO 5  I=2,N
          E(I-1) = E(I)
```

```fortran
    5 CONTINUE
      E(N) = ZERO
      B = ZERO
      F = ZERO
      DO 60  L=1,N
         J = 0
         H = FDELP*(DABS(D(L))+DABS(E(L)))
         IF (B.LT.H) B = H
C                                        LOOK FOR SMALL SUB-DIAGONAL ELEMENT
         DO 10  M=L,N
            K=M
            IF (DABS(E(K)) .LE. B) GO TO 15
   10    CONTINUE
   15    M = K
         IF (M.EQ.L) GO TO 55
   20    IF (J .EQ. 30) GO TO 85
         J = J+1
         L1 = L+1
         G = D(L)
         P = (D(L1)-G)/(E(L)+E(L))
         R = DSQRT(P*P+ONE)
         D(L) = E(L)/(P+DSIGN(R,P))
         H = G-D(L)
         DO 25 I = L1,N
            D(I) = D(I)-H
   25    CONTINUE
         F = F+H
C                                        QL TRANSFORMATION
         P = D(M)
         C = ONE
         S = ZERO
         MM1 = M-1
         MM1PL = MM1+L
         IF (L.GT.MM1) GO TO 50
         DO 45 II=L,MM1
            I = MM1PL-II
            G = C*E(I)
            H = C*P
            IF (DABS(P).LT.DABS(E(I))) GO TO 30
            C = E(I)/P
            R = DSQRT(C*C+ONE)
            E(I+1) = S*P*R
            S = C/R
            C = ONE/R
            GO TO 35
   30       C = P/E(I)
            R = DSQRT(C*C+ONE)
            E(I+1) = S*E(I)*R
            S = ONE/R
            C = C*S
   35       P = C*D(I)-S*G
            D(I+1) = H+S*(C*G+S*D(I))
            IF (IZ .LT. N) GO TO 45
C                                        FORM VECTOR
            DO 40 K=1,N
               H = Z(K,I+1)
               Z(K,I+1) = S*Z(K,I)+C*H
               Z(K,I) = C*Z(K,I)-S*H
   40       CONTINUE
   45    CONTINUE
```

```fortran
   50       E(L) = S*P
            D(L) = C*P
            IF (DABS(E(L)) .GT.B) GO TO 20
   55       D(L) = D(L) + F
   60 CONTINUE
C                                        ORDER EIGENVALUES AND EIGENVECTORS
        DO  80  I=1,N
            K = I
            P = D(I)
            IP1 = I+1
            IF (IP1.GT.N) GO TO 70
            DO 65  J=IP1,N
               IF (D(J) .GE. P) GO TO 65
               K = J
               P = D(J)
   65       CONTINUE
   70       IF (K.EQ.I)  GO TO 80
            D(K) = D(I)
            D(I) = P
            IF (IZ .LT. N) GO TO 80
            DO 75 J = 1,N
               P = Z(J,I)
               Z(J,I) = Z(J,K)
               Z(J,K) = P
   75       CONTINUE
   80 CONTINUE
        GO TO 9005
   85 IER = 128+L
 9000 CONTINUE
        CALL UERTST(IER,6HEQRT2S)
 9005 RETURN
        END
C   IMSL ROUTINE NAME    - UERTST
C
C-------------------------------------------------------------------------
C
C   COMPUTER              - IBM/SINGLE
C
C   LATEST REVISION       - JANUARY 1, 1978
C
C   PURPOSE               - PRINT A MESSAGE REFLECTING AN ERROR CONDITION
C
C   USAGE                 - CALL UERTST (IER,NAME)
C
C   ARGUMENTS    IER      - ERROR PARAMETER. (INPUT)
C                             IER = I+J WHERE
C                             I = 128 IMPLIES TERMINAL ERROR,
C                             I =  64 IMPLIES WARNING WITH FIX, AND
C                             I =  32 IMPLIES WARNING.
C                             J = ERROR CODE RELEVANT TO CALLING
C                                 ROUTINE.
C                NAME     - A SIX CHARACTER LITERAL STRING GIVING THE
C                             NAME OF THE CALLING ROUTINE. (INPUT)
C
C   PRECISION/HARDWARE    - SINGLE/ALL
C
C   REQD. IMSL ROUTINES   - UGETIO
C
C   NOTATION              - INFORMATION ON SPECIAL NOTATION AND
C                             CONVENTIONS IS AVAILABLE IN THE MANUAL
```

80

```
C                         INTRODUCTION OR THROUGH IMSL ROUTINE UHELP
C
C
C    REMARKS           THE ERROR MESSAGE PRODUCED BY UERTST IS WRITTEN
C                      ONTO THE STANDARD OUTPUT UNIT. THE OUTPUT UNIT
C                      NUMBER CAN BE DETERMINED BY CALLING UGETIO AS
C                      FOLLOWS..   CALL UGETIO(1,NIN,NOUT).
C                      THE OUTPUT UNIT NUMBER CAN BE CHANGED BY CALLING
C                      UGETIO AS FOLLOWS..
C                                    NIN = 0
C                                    NOUT = NEW OUTPUT UNIT NUMBER
C                                    CALL UGETIO(3,NIN,NOUT)
C                      SEE THE UGETIO DOCUMENT FOR MORE DETAILS.
C
C    COPYRIGHT          - 1978 BY IMSL, INC. ALL RIGHTS RESERVED.
C
C    WARRANTY           - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN
C                         APPLIED TO THIS CODE. NO OTHER WARRANTY,
C                         EXPRESSED OR IMPLIED, IS APPLICABLE.
C
C-------------------------------------------------------------------------
C
      SUBROUTINE UERTST (IER,NAME)
C                                SPECIFICATIONS FOR ARGUMENTS
      INTEGER             IER
      INTEGER*2           NAME(3)
C                                SPECIFICATIONS FOR LOCAL VARIABLES
      INTEGER*2           NAMSET(3),NAMEQ(3)
      DATA                NAMSET/2HUE,2HRS,2HET/
      DATA                NAMEQ/2H  ,2H  ,2H  /
C                                FIRST EXECUTABLE STATEMENT
      DATA                LEVEL/4/,IEQDF/0/,IEQ/1H=/
      IF (IER.GT.999) GO TO 25
      IF (IER.LT.-32) GO TO 55
      IF (IER.LE.128) GO TO 5
      IF (LEVEL.LT.1) GO TO 30
C                                PRINT TERMINAL MESSAGE
      CALL UGETIO(1,NIN,IOUNIT)
      IF (IEQDF.EQ.1) WRITE(IOUNIT,35) IER,NAMEQ,IEQ,NAME
      IF (IEQDF.EQ.0) WRITE(IOUNIT,35) IER,NAME
      GO TO 30
    5 IF (IER.LE.64) GO TO 10
      IF (LEVEL.LT.2) GO TO 30
C                                PRINT WARNING WITH FIX MESSAGE
      CALL UGETIO(1,NIN,IOUNIT)
      IF (IEQDF.EQ.1) WRITE(IOUNIT,40) IER,NAMEQ,IEQ,NAME
      IF (IEQDF.EQ.0) WRITE(IOUNIT,40) IER,NAME
      GO TO 30
   10 IF (IER.LE.32) GO TO 15
C                                PRINT WARNING MESSAGE
      IF (LEVEL.LT.3) GO TO 30
      CALL UGETIO(1,NIN,IOUNIT)
      IF (IEQDF.EQ.1) WRITE(IOUNIT,45) IER,NAMEQ,IEQ,NAME
      IF (IEQDF.EQ.0) WRITE(IOUNIT,45) IER,NAME
      GO TO 30
   15 CONTINUE
C                                CHECK FOR UERSET CALL
      DO 20 I=1,3
         IF (NAME(I).NE.NAMSET(I)) GO TO 25
   20 CONTINUE
      LEVOLD = LEVEL
```

```
      LBVEL = IER
      IER = LEVOLD
      IF (LEVEL.LT.0) LEVEL = 4
      IF (LEVEL.GT.4) LEVEL = 4
      GO TO 30
   25 CONTINUE
      IF (LBVEL.LT.4) GO TO 30
C                                   PRINT NON-DEFINED MESSAGE
      CALL UGETIO(1,NIN,IOUNIT)
      IF (IEQDF.EQ.1) WRITE(IOUNIT,50) IER,NAMEQ,IEQ,NAME
      IF (IEQDF.EQ.0) WRITE(IOUNIT,50) IER,NAME
   30 IEQDF = 0
      RETURN
   35 FORMAT(19H *** TERMINAL ERROR,10X,7H(IER = ,I3,
     1        20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
   40 FORMAT(36H *** WARNING WITH FIX ERROR  (IER = ,I3,
     1        20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
   45 FORMAT(18H *** WARNING ERROR,11X,7H(IER = ,I3,
     1        20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
   50 FORMAT(20H *** UNDEFINED ERROR,9X,7H(IER = ,I5.
     1        20H) FROM IMSL ROUTINE ,3A2,A1,3A2)
C                                   SAVE P FOR P = R CASE
C                                   P IS THE PAGE NAME
C                                   R IS THE ROUTINE NAME
   55 IEQDF = 1
      DO 60 I=1,3
   60 NAMEQ(I) = NAME(I)
   65 RETURN
      END
C   IMSL ROUTINE NAME    - UGETIO
C
C-----------------------------------------------------------------------
C
C   COMPUTER             - IBM/SINGLE
C
C   LATEST REVISION      - JANUARY 1, 1978
C
C   PURPOSE              - TO RETRIEVE CURRENT VALUES AND TO SET NEW
C                          VALUES FOR INPUT AND OUTPUT UNIT
C                          IDENTIFIERS.
C
C   USAGE                - CALL UGETIO(IOPT,NIN,NOUT)
C
C   ARGUMENTS    IOPT    - OPTION PARAMETER. (INPUT)
C                          IF IOPT=1, THE CURRENT INPUT AND OUTPUT
C                          UNIT IDENTIFIER VALUES ARE RETURNED IN NIN
C                          AND NOUT, RESPECTIVELY.
C                          IF IOPT=2 (3) THE INTERNAL VALUE OF
C                          NIN (NOUT) IS RESET FOR SUBSEQUENT USE.
C                NIN     - INPUT UNIT IDENTIFIER.
C                          OUTPUT IF IOPT=1, INPUT IF IOPT=2.
C                NOUT    - OUTPUT UNIT IDENTIFIER.
C                          OUTPUT IF IOPT=1, INPUT IF IOPT=3.
C
C   PRECISION/HARDWARE   - SINGLE/ALL
C
C   REQD. IMSL ROUTINES  - NONE REQUIRED
C
C   NOTATION             - INFORMATION ON SPECIAL NOTATION AND
C                          CONVENTIONS IS AVAILABLE IN THE MANUAL
```

```
C                          INTRODUCTION OR THROUGH IMSL ROUTINE UHELP
C
C                 EACH IMSL ROUTINE THAT PERFORMS INPUT AND/OR OUTPUT
C                 OPERATIONS CALLS UGETIO TO OBTAIN THE CURRENT UNIT
C       REMARKS   IDENTIFIER VALUES. IF UGETIO IS CALLED WITH IOPT=2 OR 3
C                 NEW UNIT IDENTIFIER VALUES ARE ESTABLISHED. SUBSEQUENT
C                 INPUT/OUTPUT IS PERFORMED ON THE NEW UNITS.
C
C                         - 1978 BY IMSL, INC. ALL RIGHTS RESERVED.
C       COPYRIGHT
C
C                         - IMSL WARRANTS ONLY THAT IMSL TESTING HAS BEEN
C       WARRANTY          APPLIED TO THIS CODE. NO OTHER WARRANTY,
C                         EXPRESSED OR IMPLIED, IS APPLICABLE.
C
C       -----------------------------------------------------------------
C
C           SUBROUTINE UGETIO(IOPT,NIN,NOUT)
C                                      SPECIFICATIONS FOR ARGUMENTS
C           INTEGER              IOPT,NIN,NOUT
C                                      SPECIFICATIONS FOR LOCAL VARIABLES
C           INTEGER              NIND,NOUTD
C           DATA                 NIND/5/,NOUTD/6/
C                                      FIRST EXECUTABLE STATEMENT
C
            IF (IOPT.EQ.3) GO TO 10
            IF (IOPT.EQ.2) GO TO 5
            IF (IOPT.NE.1) GO TO 9005
            NIN = NIND
            NOUT = NOUTD
            GO TO 9005
        5   NIND = NIN
            GO TO 9005
       10   NOUTD = NOUT
     9005   RETURN
            END
```